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A META-ANALYSIS OF CORROSION STUDIES FOR MARITIME PATROL AND RECONNAISSANCE AIRCRAFT (MPRA)

by

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September 2016

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It is very important to find means and methods to reduce maritime patrol and reconnaissance aircraft (MPRA) corrosion costs. This thesis examines recent Department of Defense (DOD) and Government Accounting Office (GAO) corrosion studies to conduct meta-analysis and make recommendations based on correlated findings. The methods adopted for this thesis consist of a literature review, heuristic flow diagram, case study selections and meta-analysis. The conclusions are that the cost of MPRA corrosion treatment and prevention is detrimental in the consumption of manpower and resources, is a high readiness degrader, and diverts funding that could be used for future programs. Corrosion treatment and prevention processes of the past may not be environmentally acceptable today. This study recommends that HAZMAT material used to combat aircraft paint/corrosion be carefully monitored and reduced to a minimum as soon as possible. Further, man-hour reduction studies are needed to optimize a balance between corrosion prevention and treatment cost and man-hours. One recommendation is to establish an international naval corrosion working group to pool talent and resources with our naval allies toward developing common corrosion tactics. An additional recommendation is to fund a comprehensive MPRA wash interval optimization study to include all MPRA-type model series aircraft.

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A META-ANALYSIS OF CORROSION STUDIES FOR MARITIME PATROL AND RECONNAISSANCE AIRCRAFT (MPRA)

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It is very important to find means and methods to reduce maritime patrol and reconnaissance aircraft (MPRA) corrosion costs. This thesis examines recent Department of Defense (DOD) and Government Accounting Office (GAO) corrosion studies to conduct meta-analysis and make recommendations based on correlated findings. The methods adopted for this thesis consist of a literature review, heuristic flow diagram, case study selections and meta-analysis. The conclusions are that the cost of MPRA corrosion treatment and prevention is detrimental in the consumption of manpower and resources, is a high readiness degrader, and diverts funding that could be used for future programs. Corrosion treatment and prevention processes of the past may not be environmentally acceptable today. This study recommends that HAZMAT material used to combat aircraft paint/corrosion be carefully monitored and reduced to a minimum as soon as possible. Further, man-hour reduction studies are needed to optimize a balance between corrosion prevention and treatment cost and man-hours. One recommendation is to establish an international naval corrosion working group to pool talent and resources with our naval allies toward developing common corrosion tactics. An additional recommendation is to fund a comprehensive MPRA wash interval optimization study to include all MPRA-type model series aircraft.

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LIST OF ACRONYMS AND ABBREVIATIONS

CONUS	continental United States
CPC IPT	Corrosion Prevention and Control Integrated Product Team
DCMA	Defense Contract Management Agency
DOD	Department of Defense
EMT	elapsed maintenance time
FST	fleet support team
FY	fiscal year
GAO	Government Accounting Office
HMAUL	hazardous material authorized usage list
IMC	Integrated Maintenance Concept
IMC/P	Integrated Maintenance Concept/Program
INWCG	International Naval Warfare Corrosion Group
MPRA	maritime patrol and reconnaissance aircraft
MSA	materiel solution analysis
MSDS	material safety data sheet
NADEP	Naval Aircraft Depot
NALCOMIS	Naval Aviation Logistics Command Management Information System
NMC	not mission capable
NWCG	International Naval Warfare Corrosion Group
OEM	original equipment manufacturer
OOMA	optimized organizational maintenance activity
PDM	periodic depot maintenance
R&D	research and development
RCM	reliability centered maintenance
ROI	return on investment
SE	Systems Engineering
TEC	type equipment code
TMS	type, model, series
TOW	time of wetness
U.S.	United States

UNA	unreported not available
USD(AT&L)	Under Secretary of Defense for Acquisition, Technology, and Logistics
USN	United States Navy

EXECUTIVE SUMMARY

The mission of Maritime Patrol and Reconnaissance Aircraft (MPRA) requires extended duration flights over vast oceans, at low and high altitudes, making the platform highly susceptible to corrosion. Tactical maneuvers conducted in the execution of the worldwide MPRA mission exposes the aircraft to a variety of temperature and humidity ranges. These environments range from tropical rainforest, to desert regions, as well as arctic and temperate coastal zones. Each area poses its own unique operational challenge, but corrosion soon becomes a major mission degrader anywhere. *The Effect of Corrosion on the Cost and Availability of Navy and Marine Corps Aviation Weapon Systems* places the "current annual cost of corrosion for DOD facilities, infrastructure, and equipment at $22.5 billion" (Herzberg et al. 2011, 1–2). Using methodology approved by the Corrosion Prevention and Control Integrated Product Team (CPC IPT), it is estimated "that the annual corrosion costs for Navy and Marine Corps aviation is $2.6 billion" (1–2).

Using a methodology approved by the CPC IPT, it is estimated that the "annual corrosion costs for Navy and Marine Corps aviation to be $3 billion" (Comptroller General of the United States 2009, iii). With increasing sophistication in aircraft, the cost of MPRA corrosion will increase.

This report describes a range of possible solutions to corrosion problems, which have strong potential for reducing MPRA maintenance corrosion man-hours and cost. Data indicates that there is still opportunity for improvement through greater cooperation between systems engineering and logistics to optimize the efficiency of MPRA corrosion activities.

There are tremendous Department of Defense (DOD) corrosion studies sponsored by congressional committees, the Government Accounting Office (GAO), military service components, academia, and private industry, several of which have been analyzed for this research. Raw MPRA corrosion maintenance man-hour data from the Naval Aviation Logistics Command Management Information System (NALCOMIS) Optimized Organizational Maintenance Activity (OOMA) also was utilized.

As the research for this report progressed, one factor became most important, reducing high corrosion control and repair man-hours and cost. It is imperative to protect and preserve the aircraft's outer barrier paint scheme; however, there are many constraints to this protection. Some of these constraints include salt-water exposure, aircraft wash intervals, organizational level panel removal and replacement requirements, and organizational level painting activities. While aircraft maintenance is critical to the safe and continual operation of the aircraft, there is an opportunity for damage and moisture intrusion. When a squadron receives a new P-8A Poseidon aircraft, it requires a lengthy in-depth acceptance inspection. This inspection involves the removal of maintenance service panels, which breaks the exterior paint barrier protection and introduces opportunity for moisture intrusion. Currently, most of these inspections are occurring at the depot maintenance facility in Jacksonville, FL, which is known for high temperatures and humidity.

Corrosion cost can be reduced by decreasing the quantity of hazardous materials procured and by extending aircraft maintenance inspections and depot requirements to intervals, which match maximum capacity. The study would review the effectiveness of current depot maintenance intervals. Even small aircraft depot interval extensions would increase the number of aircraft in the squadrons, increasing readiness. In addition, aircraft depot scheduling should be reviewed for optimal scheduling of materials used to conduct repairs and staffing constraints. Depot capacity should also be a part of the study. The practice of storing aircraft outside on the ramp for weeks increases the cost of increased corrosion inspections and repairs required during depot. Optimizing aircraft flow through the depot and associated aircraft hangar/ramp space requirements will avoid large numbers of aircraft being stored outside in the elements awaiting depot induction.

A quick look at MPRA corrosion control data suggests that new MPRA are experiencing high corrosion labor hours almost at the level of older MPRA. Further research into why this situation is occurring is necessary and very important. High corrosion costs can deprive the warfighter of new and future capabilities and put operational readiness at risk due to equipment readiness degradation. The panel removal during aircraft acceptance inspections is a corrosion intrusion opportunity. MPRA data suggests extension of the current 28-day aircraft wash cycle to 112 days, which would reduce maintenance man-hours and increase aircraft availability by extending inspection intervals. This report addresses how small improvements in wash intervals can greatly improve the availability of an aircraft for tasking.

In addition to wash intervals, paint interval studies are required to optimize organizational level (O) corrosion control activities across all MPRA. Organizational painting activities in many studies recommend restricted painting activities. Maintenance would monitor the aircraft material condition and determine when a paint/corrosion tiger team action is required. The advantage to this approach is that squadrons can greatly reduce stockpiles of hazardous paints, thinners, and solvents, leaving them environmentally greener while reducing the overall MPRA outfitting and refitting cost of paint, training, manpower, and related materials at each squadron.

Finally, allied and NATO Navy components worldwide face environmental challenges similar to the United States. One possible solution to the challenges is to organize interested parties to form an International Warfare Corrosion Group (NWCG) with the main goal of reducing the total ownership cost of corrosion across our collective forces.

References

Comptroller General of the United States. 2009. *Theory and Practice of Cost Estimating for Major Acquisitions.* Washington, DC: U.S. Government Accountability Office.

Herzberg, Eric F., Trevor K. Chan, Paul N. Chang, Mitchell L. Daniels, and Norman T. O’Meara. 2011. *The Effects of Corrosion on the Cost and Availability of Navy and Marine Corps Aviation Systems*. Report OSDOGT1. Washington, DC: Office of the Secretary of Defense.

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I. INTRODUCTION

A. BACKGROUND

The mission of Maritime Patrol and Reconnaissance Aircraft (MPRA) is to operate as long-range anti-submarine warfare (ASW), anti-surface warfare (ASuW), intelligence, surveillance, and reconnaissance (ISR) aircraft capable of broad-area, global maritime, and littoral operations. MPRA routinely fly in an open sea environment for extended periods. Thus, MPRA operate in high levels of ocean moisture and sea salts, which cause aircraft corrosion. High corrosion treatment and prevention cost can rob the warfighter of new and future capabilities and put operational readiness at risk due to equipment readiness degradation.

Historically, combating corrosion on MPRA consumes vast amounts of budget, scores of man-hours, and requires the use of very dangerous and toxic chemicals. In the P-8A community, a complete and comprehensive list of these materials is contained in the hazardous materials allowance list (HMAUL). By contract, the original HMAUL delivered to the United States (U.S.) Navy by Boeing was enormous with huge quantities and volumes. The cost for the procurement, storage, and disposal of HMAUL was very expensive and labor intensive. Many of these chemicals are carcinogens and require special handling and protective equipment. In many cases, they have short shelf lives and become unstable quickly. Reduction of the P-8A HMAUL items and current inventories on hand is a vital part of this analysis.

The two most important MPRA corrosion factors are cost and decreased readiness. Corrosion costs are increasing annually across the MPRA, while at the same time, decreasing the material readiness of its fleet. According to the *Theory and Practice of Cost Estimating for Major Acquisitions Comptroller General of the United States*, the U.S. Navy and Marine Corps aviation corrosion cost is as high as $3 billion. Costs of this magnitude strain resources and decrease readiness.

Decreased readiness is due to aircraft being unavailable for service to facilitate corrosion treatment and prevention. In addition, corrosion maintenance actions increase labor and material cost and require additional aircraft painting, which drives an increased use of hazardous materials. These dependencies all require effective coordination between logistics and engineering to develop and implement optimal corrosion fighting procedures. This report is limited to MPRA corrosion impacts, which is very important to the MPRA program.

B. PURPOSE

This research will analyze a subset of existing Department of Defense (DOD) and Government Accounting Office (GAO) corrosion studies, which have the potential to reduce MPRA corrosion costs. To reduce the scope from hundreds of studies, commercial, academic, DOD and GAO, this research will not include corrosion studies outside of DOD and GAO, and is limited in scope to the MPRA only.

- Why is this work important? If a solution to the high cost of MPRA corrosion is not found, then corrosion costs will continue to escalate and aircraft readiness will continue to degrade. The problem of high corrosion prevention and treatment labor and material cost has been an on-going serious issue facing all DOD programs per United States General Accounting Office. 2003. *Opportunities to Reduce Corrosion Costs and Increase Readiness*. GAO-03-753. Washington DC: United States General Accounting Office.

C. RESEARCH QUESTION

The following research question will be explored to address the problem of curbing the continually rising costs of corrosion and increasing the number of MPRA for the fleet:

- What corrosion reduction methodologies exist in the DOD and GAO corrosion studies that will assist MPRA with corrosion and prevention planning?

D. BENEFITS OF STUDY

The benefits of the study are an attempt to recapitalize MPRA corrosion funding and to improve aircraft readiness thorough a better understanding of the MPRA corrosion issues.

MPRA are long-range ASW, ASuW, ISR aircraft capable of broad-area, maritime, and littoral operations. These operations often require the aircraft to spend long hours patrolling oceans and waterways day and night. Much of MPRA patrol time is spent at very low altitudes.

The procurement cost of these platforms is in the hundreds of million dollars each, so they are procured in relatively small numbers. When aircraft are out of service due to corrosion related activities, it has an immediate operational effect in the form of reduced readiness for tasking aircraft.

The MPRA mission requirements make the platform highly susceptible to corrosive elements.

This report is organized into the following chapters.

Chapter I: Introduction describes the mission and importance of and the degrading effect corrosion has on operating cost in labor and materials. This chapter also contains the purpose and research questions and benefits of the research.

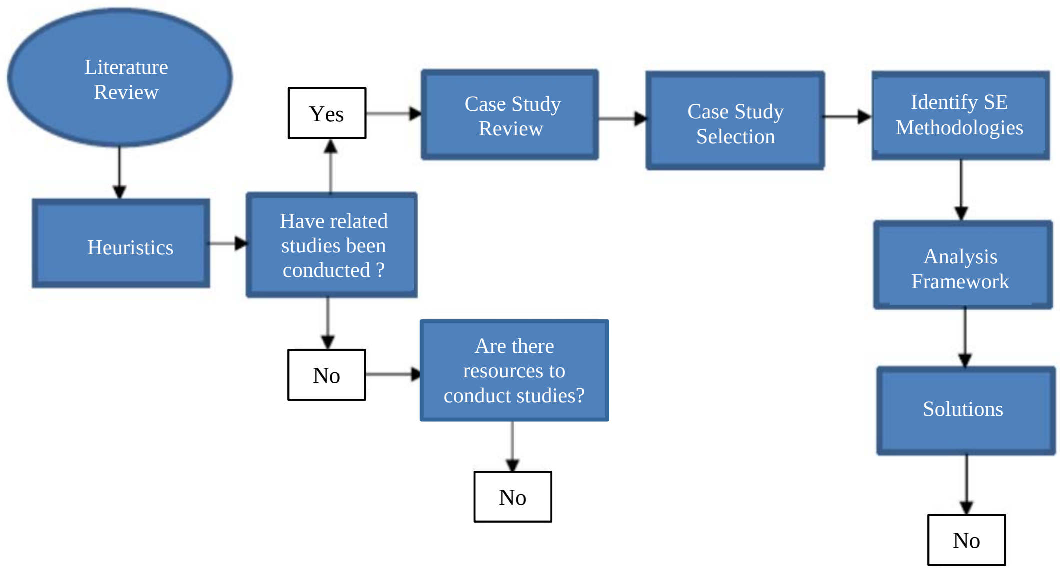
Chapter II: Scope/Methodology explores the literature review and the case study review selection process. Methods to be used in the analysis of findings, as well as the data analysis used to develop graphs, charts and findings.

Chapter III: Analysis of Data discusses aircraft wash cycles, a major corrosion cost labor driver and aircraft readiness impacts. Charts, graphs, and illustrations are provided as a visual depiction of MPRA corrosion affects relative to aircraft wash and paint cycle times.

Chapter IV: Conclusions and Recommendations state that MPRA have high corrosion prevention to corrosion treatment man-hours as reported by NALCOMIS. High corrosion prevention man-hours will lower MPRA availability due to aircraft being removed from service to undergo corrosion prevention maintenance. The recommendations include HAZMAT material reductions, the extension of MPRA wash and paint intervals, and the need for follow on MPRA paint and corrosion man-hour reduction studies.

II. SCOPE/METHODOLOGY

The literature review is a thematic evaluation of published literature organized around current DOD corrosion issues, rather than a study of corrosion effects through the decades. This evaluation is shown in Figure 1.



The relevance of the block diagram flow chart is to provide a simplified visual presentation, which outlines the process flow for the selection of case studies. The system engineering methods were utilized, as well as the framework to conduct the analysis.

Figure 1. Literature Review Top Level Objectives Diagram

A. LITERATURE REVIEW

There are hundreds of articles, books and studies, which may or may not be of relevance to this research. The scope of corrosion cost and effects DOD–wide is too broad a scope for any one research report, so a means was necessary to narrow the topic and the associated research. Reports having the most relevance and potential for reducing MPRA corrosion cost were selected for the literature review. This report is limited to researching methods to possibly recoup MPRA corrosion cost, with a focus on aircraft wash, paint requirements, HMAUL reduction, aircraft, acceptance man-hours, corrosion prevention, and treatment man-hours optimization as areas for reducing cost and improving aircraft readiness**.**

During the review, 117 commercial, academic, DOD, and GAO corrosion studies were discovered and eight were selected for this research. The technical approach consisted of a flow process to determine which studies would be included into this research. DOD and GAO MPRA corrosion studies conducted recently were given high consideration for moving on to case study review. This research did not have funding to conduct new or follow-on corrosion case studies. To the maximum extent possible, data from the accepted case studies utilized MPRA as test assets. The focus of the research was on corrosion studies that provided data relevant to solutions to reduce MPRA corrosion cost, while not having an adverse effect on aircraft readiness.

Observed from the estimates contained in the GAO-13-661 report and OIG Report No. 97-181, the DOD's annual cost for corrosion of Navy and Marine Corps aircraft is a very serious problem (Government Accounting Office 2013; Office of the Inspector General 1997). The results imply that annual corrosion costs for DOD facilities are estimated at $9 billion to $20 billion. Estimates are also available that state the annual corrosion costs for Navy and Marine Corps aviation are $3 billion.

The accepted method is to include direct, material, and training cost. Thus, this author concluded that an opportunity exists to recover a percentage of that cost. Further analysis is required to create an estimate. However, extending aircraft wash, paint intervals, depot scheduling and organizational maintenance corrosion, and aircraft painting can be significantly reduce cost and improve aircraft availability, if optimized. The results imply that MPRA wash cycles could be extended greatly without a significant increase in corrosion. The reports suggest an aircraft wash interval extension could have tactical advantages as well. The reports suggest that no corrosion degradation will occur from switching from a 28-day aircraft wash to 112-day wash. Sensor data was obtained approximately every three months over the course of one year. The study documented the benefits and possibility of prolonging aircraft wash intervals, which may well provide significant labor and cost savings. This data was very useful in scoping the level of corrosion control effort for all MPRA type aircraft. The data suggest that the P-3 airframe has reached its maximum useful service life and is becoming very expensive and man-hour intensive to support, based on the 1997 OIG report, *U.S. Navy Aircraft Corrosion Prevention and Control Program*, DOD's annual cost for corrosion of Navy and Marine Corps aircraft, (Government Accounting Office 2013; Office of the Inspector General 1997). The amount and level of corrosion found in the MPRA P-3 aircraft were among top 10 degraders observed from this study. The surprise in the analysis was the P-8A data. The results imply that the P-8A aircraft, while new, has an unusually high number of corrosion control man-hours against each aircraft, and the number is rising.

Numerous related corrosion studies were uncovered that had direct relevance to the research conducted. Others were close but required additional resources for further research, so were not included due to funding and scope. Current and related corrosion studies were accepted and forwarded to case study review.

The selected reports for this case study are the following.

- Abbott, W. H., Owen Jett, Molly Statham, and James Sawinski. 2007. "Corrosion Sensors for Evaluation of Wash Intervals on Aircraft." *Proceedings of Tri Service Corrosion Conference, Denver*.

- Abbott, W. H., Battelle Columbus, and Michael Beals. 2009. "A Study of Wash Intervals on Navy P3 Aircraft Using Corrosion Sensors." Technical Session at the DOD Corrosion Conference 2009, Gaylord National, Washington, DC, August 1–14.

- Abbott, W. H., and Richard Kinzie. 2006. "Aircraft Corrosion Sensing and Monitoring Program." *Proceedings from Aging Aircraft Conference, Atlanta, Georgia*.

- Abbott, W. H., and Kinzie, Richard. 2007. "Effects of Wash Rinse Intervals on Corrosion: Early Results of a Ground Based Study." Paper presented at Aging Aircraft Conference, Atlanta, Georgia.

- Forman et al. 2008. *LMI Annual Cost of Corrosion for Navy and Marine Corps Aviation Equipment*. Report MEC70T3. Washington, DC: LMI Government Consulting.

- Office of the Inspector General. 1997. *U.S. Navy Aircraft Corrosion Prevention and Control Program*. Report. No. 97-181. Washington, DC: Department of Defense.

- Pate, George. 2008. *P-3 Corrosion Study*. Case Study. Jacksonville, FL: NAVAIR.
- United States General Accounting Office. 2003. *Opportunities to Reduce Corrosion Costs and Increase Readiness*. GAO-03-753. Washington, DC: United States General Accounting Office.

B. ASCERTAIN HEURISTICS

Heuristics sometimes are educated guesses, a person's intuitive judgments, or just common sense. Heuristics is a general way of solving a problem. The problem early on was where to start? How to determine which systems engineering (SE) method would provide the desired solutions. Since there are hundreds of well-documented corrosion studies, the problem becomes how to glean the data, which will best serve this research. The Heuristic or common sense approach was to find a practical approach to visualize the process. The creation of a mental picture of objectives and process was critical in navigating through the literature review and subsequent analysis and findings.

C. CASE STUDY REVIEW/SELECTION

This research examines numerous methods aimed at the reduction of MPRA corrosion costs, which include methods to protect and preserve the outer barrier paint, such as fresh water rinses versus aircraft washes, or revised and extended aircraft wash schedules. The process narrowed the selection to eight studies. A description of the studies used follows.

A 2003 GAO report, *Opportunities to Reduce Corrosion Costs and Increase Readiness*, found that opportunities existed to reduce corrosion costs and increase readiness. The results of this study recommended measures to reduce corrosion control costs by protecting the outer barrier paint scheme, as well as to reduce or eliminate conflicting corrosion policies and priorities. It cited the redundancy in multiple DOD corrosion offices, different policies, and varying funding channels challenge operational commands in their planning and execution of operational and aircraft maintenance requirements (United States General Accounting Office 2003). Corrosion organizations sometimes conflicted with operational commanders, which reduced the effectiveness of organizational maintenance planning.

Through the research of Abbott and Kinzie (2006), Abbott and Kinzie (2007), and Abbott, Columbus, and Beals (2009), came the generalized conclusion that far too many maintenance man-hours were being devoted to battling corrosion. The corrosion prevention and correction maintenance man-hours create large periods of aircraft out-of-service time when MPRA are not available for tasking. While corrosion maintenance is critical to the health and longevity of MPRA, an optimal solution would reduce the amount of corrosion maintenance days.

The U.S. Navy corrosion man-hours used for this report came from the NALCOMIS Optimized Organizational Maintenance Activity (OOMA) database, which stores raw U.S. Navy-wide aircraft maintenance data. This data was to scope the level of the MPRA corrosion treatment/prevention effort. Maritime Patrol and reconnaissance aircraft corrosion man-hours for the period of evaluation were from January 2012 to December 2013. Descriptive statistical analysis of NALCOMIS raw MPRA maintenance corrosion man-hour data provided graphs and data in Microsoft Excel. The corrosion preventative man-hours were 120,000. The corrosion treatment man-hours for the same time period were 13,333. A number of things make this data very interesting. First, the 120,000 corrosion prevention hours greatly increases the MPRA number of aircraft unavailable to conduct mission tasking due to corrosion by days. The 120,000 corrosion prevention man-hours, along with the 13,333 corrosion treatment man-hours, are not in an optimal relationship per findings contained in the 2003 GAO report, *Opportunities to Reduce Corrosion Costs and Increase Readiness*. What are the driving factors in the 120,000 corrosion prevention man-hours? Can the man-hours be reduced? Can MPRA readiness be improved by reducing corrosion prevention man-hours? What is the labor and material cost associated with MPRA corrosion man-hours? These topics are incredibly fascinating and deserve focus for the remainder of the research.

Other studies examined were the *LMI Annual Cost of Corrosion for Navy and Marine Corps Aviation Equipment* study, the *Corrosion Prevention and Control Integrated Product Team Proposed Method and Structure for Determining the Cost of Corrosion for the Department of Defense* study, as well as the *P-8A Hazardous Material Allowance Usage List* (HMAUL).

The LMI study measured the effect corrosion had on the availability of all DOD aviation systems and the effect it had on the costs of Navy, Marine Corps, and Air Force aviation systems. This report used both the costs and aircraft availability effects of corrosion for Navy and Marine Corps aviation equipment using FY2008 and FY2009 as a measurement baseline.

The CP IPT corrosion cost study used *the Corrosion Prevention and Control Integrated Product Team Proposed Method and Structure for Determining the Cost of Corrosion for the Department of Defense* as a guide for costing.

The P-8A HMAUL was a study initiated to gain insight to corrosion material cost outlined in the LMI study. Material cost related to corrosion prevention and treatment were major cost drivers in the LMI study, as well as the 2013 GAO report, *Defense Management, DOD Should Enhance Oversight of Equipment Related Corrosion Projects*. A significant cost driver for the MPRA corrosion material solution is the P-8A HMAUL size, volume, and environmental considerations. The P-8A HMAUL contains the allowance for all paint, thinners, and chemicals procured for the use by organizational level maintenance for painting and the treatment of aircraft corrosion.

The 2013 GAO report, *Defense Management, DOD Should Enhance Oversight of Equipment Related Corrosion Projects*, made the following recommendations:

- To improve the DOD's corrosion-prevention and control program, and to enhance its oversight of the status and potential benefits of its equipment-related corrosion projects, the USD (AT&L) should require the Director, Corrosion Policy and Oversight Office, to revise the DOD Corrosion Prevention and Mitigation Strategic Plan or other guidance to require that the military departments include in all follow-on reports the details of measures of achievement other than ROI, such as the features, results, and potential benefits of the project.

- To improve the DOD's corrosion-prevention and control program, and to ensure consistent reporting for all equipment-related corrosion projects, the USD (AT&L) should require the Director, Corrosion Policy and Oversight Office, to revise guidance to specify how project managers should report the ROI for discontinued projects. (Government Accounting Office 2013).

Again, this research relied on the NALCOMIS OOMA corrosion data entries for direct labor costs in an attempt to correlate the predictions and findings of Abbott, Kinzie, and Columbus. Since NALCOMIS OOMA corrosion data is raw data as reported by the fleet operators, using inductive and deductive reasoning proposed a different set of actual MPRA corrosion man-hour metrics.

As stated in the Department of the Navy's Response to the Department of Defense Inspector General (DODIG), *Draft Report on U.S. Navy Aircraft Corrosion Prevention and Control Program* (1997), it was determined that the Navy "painted its aircraft more than needed at the organizational level." Furthermore, in Appendix B of the same report, the DOD issued *Quick-Reaction Report on Repainting of the C-5 Aircraft*, on September 29, 1994, which stated that the U.S. Air Force incurred unnecessary costs of approximately $59.3 million over the six-year Future Years Defense Program, by prematurely painting C-5 aircraft. It is clear to see that a reduction in premature painting has the potential to create great savings, which could benefit the MPRA program.

Creditability in cost predictions have been studied and highlighted many times. The method used to measure costs for this research derives from a well-known and acceptable source, *The Theory and Practice of Cost Estimating for Major Acquisitions* from the Comptroller General of the United States. These characteristics are still valid and contained in most cost analyses.

Best practices require precise and verifiable cost estimates. These practices over time have come to represent the acceptable standard used to provide cost estimations to Congress and other senior leadership.

D. RESEARCH METHOD

A literature review was conducted and alternate solutions were investigated. A meta-analysis review of selected DOD corrosion studies was conducted seeking relevant facts to obtain correlations which could lead to a unified decision point based on facts. A model was developed in the form of a block diagram to visualize the process flow. Findings were integrated and decomposed to include safety, health, and environmental considerations. Other SE methods employed were heuristics to determine a common sense process flow and statistical correlation using raw OOMA NALCOMIS data to show how well the findings contained in the literature review compare with fleet reported raw corrosion data. SEBoK notes that "it focuses on holistically and concurrently discovering and understanding stakeholder needs; exploring opportunities; documenting requirements; and synthesizing, verifying, validating, deploying, sustaining and evolving solutions while considering the complete problem, from system concept exploration through system disposal" in a comment posted to the SEBoK discussion board posted on December 18, 2015 (SEBoK 2015).

E. DATA ANALYSIS FRAMEWORK

As previously mentioned, the Naval Aviation Logistics Command Management Information System (NALCOMIS) is an information system, which collects and stores aviation maintenance information. It was used because it provides real-time, raw corrosion MPRA data provided by fleet maintenance operators. It is searchable by aircraft type and maintenance action performed, which includes all corrosion maintenance labor. NALCOMIS features are easy to use. Raw data from NALCOMIS is exported into Microsoft Excel for further analysis, generation of graphs, displays, and reports. Corrosion data and findings are extracted from current and recent DOD and GAO corrosion studies. Corrosion prevention and corrective man-hour raw data is extracted from OOMA and placed in Excel spreadsheets to create graphs and charts used to conduct statistical correlation between findings listed in Abbott and Kinzie (2006), Abbott and Kinzie (2007), Abbott, Columbus, and Beals (2009), and Forman et al. (2008) contained in this report. Correlations between corrosion prevention and corrective man-hour data are also compared to observe effects in efficiency and aircraft readiness. Aircraft acceptance man-hour raw data will be extracted from OOMA to observe effects in efficiency and aircraft readiness.

F. SOLUTIONS/SUMMARY

During the literature review, four main areas of interest evolved, all having the potential to influence the problem statement: aircraft wash cycles, aircraft painting, the

HMAUL, and aircraft acceptance inspection man-hours. These four items not only have great potential for cost savings but also have secondary benefits, such as increased readiness, labor hour savings, and increased environmental occupational safety if integrated properly.

Some data suggest that the labor hours and costs associated with aircraft wash cycles, paint intervals, the HMAUL, and acceptance inspections are very high. Observed from the estimates contained in the 2013 GAO report, *Report to Congressional Requestors. Defense Management. DOD Should Enhance Oversight of Equipment Related Corrosion Projects*, and the 1997 OIG report, *U.S. Navy Aircraft Corrosion Prevention and Control Program*, DOD's annual cost for corrosion of Navy and Marine Corps aircraft is a very serious problem (Government Accounting Office 2013; Office of the Inspector General 1997).

It is well documented throughout DOD and DON that corrosion cost is unsupportable at current levels long term (Office of the Inspector General 1997).

The next chapter reviews the data discovered in the case review relevant to the four main areas of interest aircraft wash intervals, organizational aircraft painting, excess HMAUL, and excessive aircraft acceptance inspections man-hours.

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III. ANALYSIS OF DATA

A. AIRCRAFT WASH CYCLES

Abbott and Kinzie (2007) conducted a series of tests in the P-3 Wash Rinse Interval Study. The results were reported in the “Effects of Wash Rinse Intervals on Corrosion: Early Results of a Ground Based Study.” Their data clearly demonstrated “that there was no significant difference in the advancement of corrosion from extending P-3 wash intervals from 28 to 112 days.” These findings provide a firm basis supporting the extension of P-3 wash intervals fleet-wide. Further studies and analysis may extend aircraft wash intervals for other types of naval aircraft as well. The Abbott and Kinzie (2007) aircraft wash interval study consisted of 14 P-3 aircraft. The intent of this study was to maintain seven aircraft at the standard 28-day wash interval. The other seven were extended to 112 days. Figure 2 shows the “dispersal of corrosion harshness detected by sensors mounted in strategically located areas measured as “Environmental Severity Index ESI” for military bases Jacksonville, Whidbey, and Kaneohe Bay (Abbott, Columbus, and Beals 2009, 10–14).

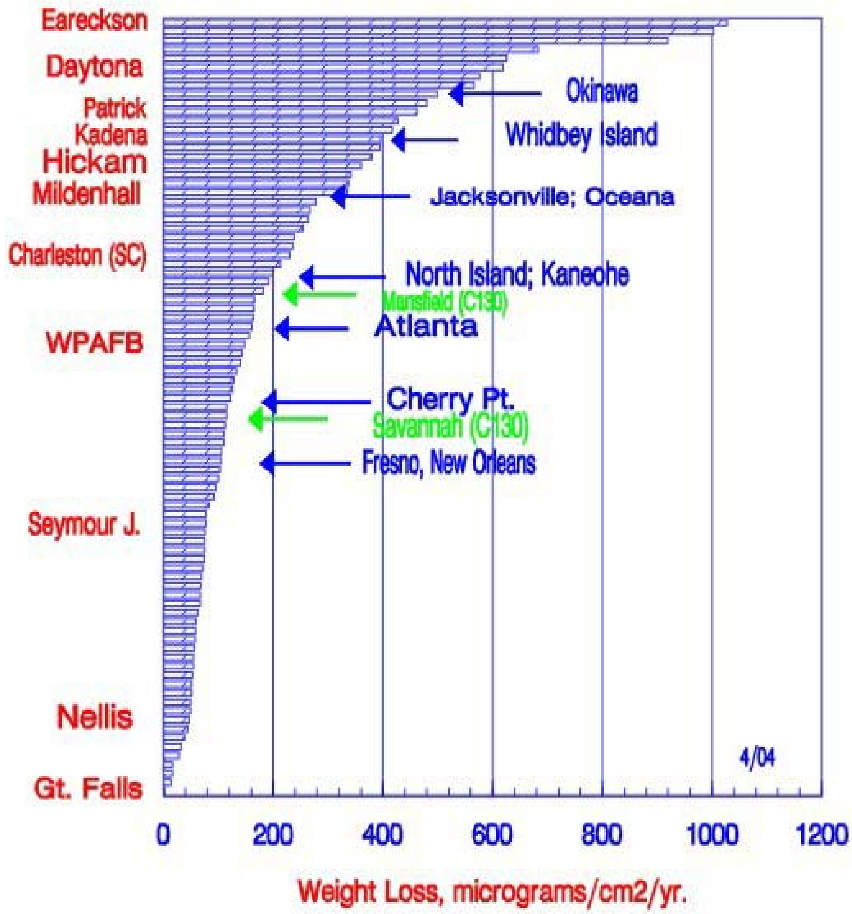


Figure 2. Corrosive Severity Distribution for Military Bases World-Wide (Based on 1 Year Weight Loss Values for 6061 T6 Aluminum). Source: Abbott, Columbus, and Beals (2009, 3).

Corrosion sensors were attached in 10 locations on each aircraft. This attachment was required because corrosion exposure and build up vary along the outer mold line of the aircraft. Thus, each corrosion sensor provides a recorded corrosion severity plotted as an out values, which are important to observing corrosion severity levels over time. Figures 3, 4, and 5 are photographs of the sensor installations at three different locations. Seven of the 10 locations were considered a must to evaluate as they are very susceptible to corrosion build up. The landing gear wheel wells were the most susceptible to moisture and exposure to corrosive contaminants.

Figure 3. Sensor Located in NG. Source: Abbott, Columbus, and Beals (2009, 4).

Figure 4. Sensor Located in MLG. Source: Abbott, Columbus, and Beals (2009, 4).

Additional sensors were mounted on external surfaces of the P-3 aircraft. All sensors functioned properly and there was no loss of sensors or data on any of the aircraft.

Figure 5. Sensor on Access Panel in Lower Surface of Left Horizontal.
Source: Abbott, Columbus, and Beals (2009, 5).

Base personnel using hand-held electronics collected data from the sensors and conducted all aircraft washes following normal procedures. The study was limited to evaluating the effects of extending the aircraft wash interval. It did not attempt to evaluate any other intervals or maintenance requirements.

A number of important results came from this study. First, it concluded that there were no significant corrosion impacts to extending the wash interval from 28 to 112 days. Prior to this study, the effects of opening panels and disrupting the integrity of the paint scheme were never included. The plotted values shown in Figures 6 through 8 are the corrosive changes against the known starting values of near zero for each sensor. The corrosion sensor kinetic responses are for the individual sensors at all locations on a single aircraft. The higher the sensor reaction, the higher the corrosive effects are for that area of the aircraft. The accumulative sensor kinetic response is measured in increments of days. Severity is then plotted over time at each aircraft sensor location line plotted and compared against sensor plots from other aircraft at different operating bases to generate Figures 6 through 8.

Figure 6 displays the sensor outputs for P-3 BUNO 159513 based at NAS Jacksonville FL. The sensors clearly illustrate high corrosion levels for the horizontal upper surface and the vertical surface over time. The sensor outputs for the horizontal lower surface are moderate but increasing over time. This type of corrosion sensor data from numerous P-3 aircraft stationed at various bases will be very helpful in generating resource loaded schedules to optimize depot maintenance requirements. The essence of the study is that aircraft parked outside in the elements at bases within coastal areas with higher humidity have higher corrosion sensor values.

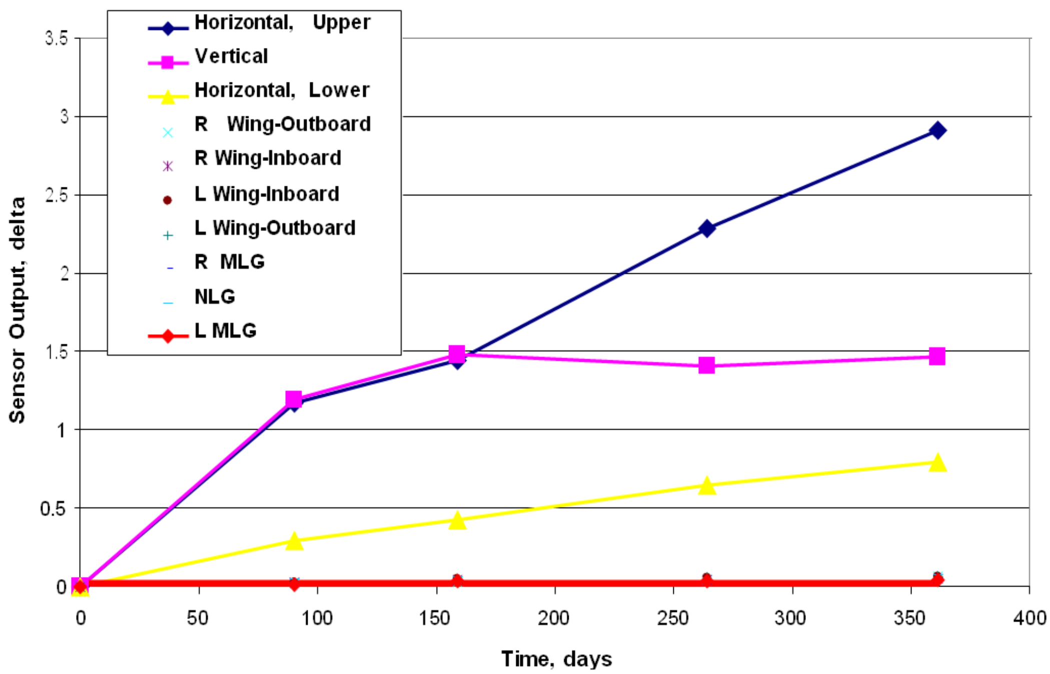


Figure 6. Sensor Output for Locations on BUNO 159513, Based at Jacksonville. Source: Abbott, Columbus, and Beals (2009, 6).

The "shielding effect," which is suspected in Figure 6, is a good example of how variances can exist. For example, areas of the aircraft, which are located within natural shadow zones, have lower corrosion sensor outputs. Aircraft stored in hangers for extended periods of time also exhibit the same shielding effect. The results of shielding can be explained simply as some bases have ample hangers to house and store aircraft out of the elements for longer periods of time. In either case, shielding from the harsh effects of weather has the potential to provide differential findings. An example of a shielding factor could be an aircraft is in storage for an extended period of time awaiting maintenance or parts. When aircraft are kept within hangers for extended periods of time, the shielding effect is more pronounced.

> The sensors on the upper horizontal consistently show the greatest cumulative corrosion and those on the more shielded lower surface show far lower rate. The latter is also an interesting example of the interaction of variables driving corrosion reactions. The lower surface may have a much higher time of wetness (TOW) compared to the upper surface, and for all other variables being equal, could have the higher corrosion rate. (Abbott, Columbus, and Beals 2009)

Abbott, Columbus, and Beals (2009) recognized, through their study, that the possibility of extending wash intervals on military aircraft existed. They also summarized that extending wash intervals would reduce direct costs, promote labor savings, and increase aircraft availability.

> Increases in aircraft availability can be particularly significant. For example, a recent study on the USAF C-130s indicated that simply increasing the wash interval from 120 to 180 days on approximately 60% of this large fleet could increase the availability/airlift capability by the equivalent of about two additional C-130s. (Abbott, Columbus, and Beals 2009, 2)

Significant readiness improvements can be obtained from even small increases in wash intervals.

MPRA are strategically located at or near coastal regions. This location provides faster response times and promotes greater training opportunities to deal with any potential maritime threat. P-3 aircraft spend a large percentage of operational flight operations over oceans at low flight levels, and are often forward deployed operating out of remote sites without aircraft rinse and adequate hanger facilities. Thus, the location severity level for the P-3 aircraft was much higher than for the C-130.

The Navy's "plan was to utilize aircraft based at two primary locations, NADEP Jacksonville (FL) and Whidbey Island (WA). While this plan was largely accomplished, several aircraft were rebased for operational reasons that included NAS Brunswick (ME), MCAS Kaneohe (HI), and a deployed aircraft," which added even further diversity to the results (Abbott, Columbus, and Beals 2009, 2). Yet, the wash interval was the same for aircraft at all locations. The data seems to indicate that aircraft stored outside at NAS Jacksonville and NAS Whidbey had higher sensor outputs, and as a result, a different corrosion prevention interval may be required. Figure 7 contains large amount corrosion samplings from all aircraft at all locations. The figure shows the wide range of responses by aircraft for the upper vertical sensor location. Of note is that the sensor readings are fairly constant and show no significant differences due to wash interval.

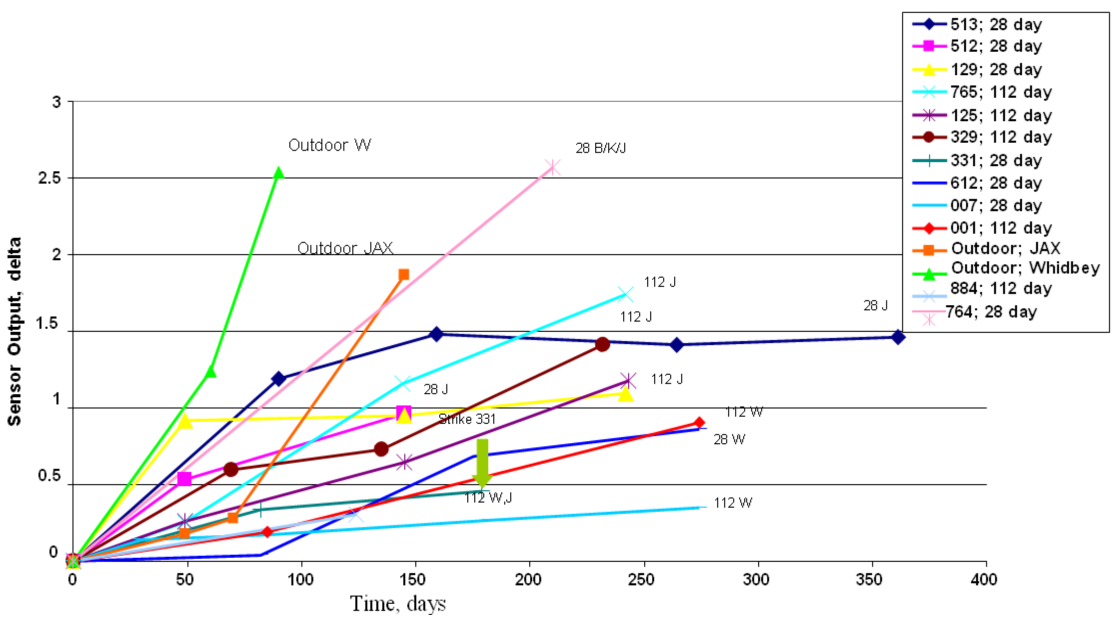


Figure 7. Sensor Response for Vertical; J=JAX; W=Whidbey; K= Kaneohe; B= Brunswick. Source: Abbott, Columbus, and Beals (2009, 8).

In Figure 8, the data contained illustrates sensor outputs from all sensors and all aircraft. The data is then compared for time duration and severity outputs. Aircraft geolocation information and data show if the aircraft was parked outside the hanger for extended periods. In addition, important data is shown for reference purposes to the ground level salt and humidity severity.

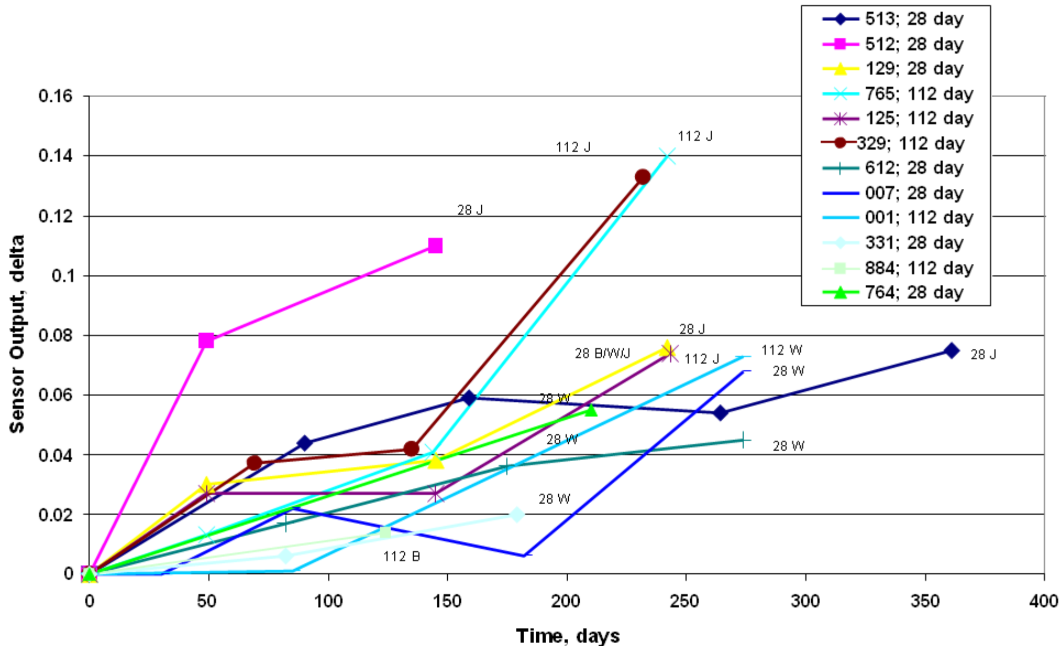


Figure 8. Sensor Response for Nose Wheel Well; J=JAX; W=Whidbey; K= Kaneohe; B= Brunswick. Source: Abbott, Columbus, and Beals (2009, 9).

B. AIRCRAFT PAINTING

In 2005, a paint interval study was conducted by Michael Beals. The study was performed at the request of the fleet to evaluate the current P-3 aircraft material readiness. P-3 aircraft, which were assigned to various Naval Air Stations, were inspected for corrosion and material condition at various intervals between depot maintenance. The aircraft were inspected by Naval Air Depot Maintenance and Fleet Support Team engineers with each aircraft graded for its material condition. “The conclusions were that the aircraft paint intervals can be extended to six years and potentially, with some more study to eight years.”

The results of the study revealed the following:

- Most aircraft inspected rated as excellent, good, or fair condition with a consistent correlation of aircraft paint condition versus age. One aircraft inspected was rated as poor (1.8 rating) but was considered as a non-representative aircraft due to deployment tempos reported by the squadron.

- Paint systems of aircraft inspected ranged from zero to 4.5 years of age and extrapolate to a six-year paint service life. A potential paint service life of eight years with moderate performance risk is achievable due to limited data available at this time. Additional inspection data of P-3 aircraft with a greater paint age population can mitigate this risk. (Beals 2005, 4)

The aircraft identified for inspection had been previously painted by Naval Aircraft Depot (NADEP) Jacksonville or Lockheed-Martin. The selection was based upon squadron or depot availability. Beal and the Fleet Support Team (FST) conducted P-3 repaint evaluations aircraft within the maintenance hangar or flight line of NAS Jacksonville to ascertain the quality of the P-3 coating system and any touch-up repair painting performed onsite. Aircraft rating was based upon the presence and/or extent of paint adhesion, paint cracking, clean ability, fluid damage, oxidation, mechanical damage, and corrosion via visual inspection of the outer mold line. Coating thickness and paint gloss readings of the fuselage and wing area were obtained using an elcometer 300 paint thickness gauge and an elcometer micro-tri gloss meter, respectively. Thickness readings were obtained for information, while gloss readings were used to quantify weatherability performance. Most notable observations of conditions leading to the degradation of the P-3 paint system are ultra-violet degradation that caused polymer oxidation and a loss of gloss and extensive coating touch-up repair because of corrosion control maintenance. No significant issues were observed related to paint cracking, fluid damage, corrosion, and clean ability of the outer aircraft paint system.

During depot maintenance, the whole aircraft is stripped of all paint and treated for corrosion and repainted. Organizational level maintenance conducts touchup and limited corrosion maintenance. There are current restrictions to aircraft paint by organization level maintenance. The Office of the Inspector General report (1997, 4) recommends that naval aviation squadrons cease painting large sections of aircraft, including terminating painting the entire aircraft in hangars. The recommendation is designed to limit organizational-level aircraft painting to minor touch-up and to locate and use existing approved facilities to perform complete painting of Navy aircraft.

The Office of the Inspector General report (1997) summarizes that “the primary objective of” painting Navy aircraft “is to protect exposed surfaces and components against corrosion and other forms of deterioration. Maintenance and repair of paint finishes are extremely important, beginning with the aircraft weapon systems development and continuing with constant monitoring throughout the life of the systems.” Naval aviation corrosion prevention and control begins at the organizational or squadron level. Aircraft organizational maintenance work center 12C is responsible for corrosion control. Maintainers from 12C inspect and treat corrosion actions, as well as being responsible for conducting aircraft washes. With corrosion discovered, the maintainer writes a maintenance action form (MAF) for the removal of the detected corrosion. Corrosion treatment can range from removing the paint and primer to inspecting the repair structure per the level of maintenance authorized. In any case, once removed, the primer and paint requires replacement to prevent further corrosion damage.

C. HAZARDOUS MATERIAL ALLOWANCE LIST

The other side of corrosion cost is the material cost. The high-cost items used in the fight against MPRA corrosion are contained in the unit’s HMAUL. The original P-8A HMAUL was delivered by Boeing and contained over 273 line items, many of which are carcinogens. Boeing HMAUL quantities were based on 737 commercial hub requirements and were too large and bulky for transport with deploying P-8A squadrons. In addition, the quantities and sizes did not match the requirements for small organizational maintenance. Findings from this research were shared with the P-8A Environmental Safety Occupational Health (ESOH) team and the P-8A FST. The goal was to reduce the size of the P-8A HMAUL contained on the original Boeing deliverables, and to make new deliverables into smaller kits better suited for organization corrosion and painting

Maintaining small quantities of necessary hazardous materials to combat corrosion is consistent in complying with existing environmental policies. This action will reduce the risk of accidental exposure to naval personnel and into the environment. The removal of only a few P-8A HMAUL items listed in this research presents an opportunity for savings in material costs and reduces the opportunity for personnel inadvertent exposure.

HMAUL items also require special handling, storage, and disposition, making the total life cycle cost of HMAUL very high. These items have a shelf life or expiration date and when ordered in large quantities, the HMAUL items frequently expire before they are needed, which results in high disposal cost. These items are also hazardous to personnel, so optimizing the quantity and volumes are a great potential for cost savings and increased safety. This study evaluated the Boeing P-8A HMAUL contained in Table 1. Detailed analysis of the HMAUL resulted in a 30% overall reduction in material with its associated cost savings.

A complete P-8A HMAUL table is presented in Appendix B.

Table 1. P-8A Hazardous Material Authorized Usage List.
Source: U.S. Navy (2013).

MSDS#	Product Name	Restricted Component	CAS#
23278	10C32; LAMINAR X-500 HARDENER	ETHYL BENZENE	100-41-4
23278	10C32; LAMINAR X-500 HARDENER	TOLUENE DIISOCYANATE	26471-62-5
23278	10C32; LAMINAR X-500 HARDENER	XYLENE	1330-20-7
88944	10P20-44; HIGH SOLIDS EPOXY PRIMER	ETHYL BENZENE	100-41-4
88944	10P20-44; HIGH SOLIDS EPOXY PRIMER	METHYL ISOBUTYL KETONE	108-10-1
88944	10P20-44; HIGH SOLIDS EPOXY PRIMER	STRONTIUM CHROMATE	7789-06-2
88944	10P20-44; HIGH SOLIDS EPOXY PRIMER	XYLENE	1330-20-7
75947	1311 KRYLON MATTE FINISH SPRAY COATING	TOLUENE	108-88-3
95283	15-71-2-51083	METHYL ETHYL KETONE	78-93-3
95283	15-71-2-51083	TOLUENE	108-88-3
88552	192 LOCTITE 7471 PRIMER T 19268	MERCAPTOBENZOTHIAZOLE	149-30-4
110910	214 LOCTITE 222 THREADLOCKER LOW STRENGTH 21465	CUMENEHYDROPEROXIDE	80-15-9
110910	214 LOCTITE 222 THREADLOCKER LOW STRENGTH 21465	SACCHARIN	81-07-2
27232	242 LOCTITE THREADLOCKER BLUE 242 REMOVABLE	CUMENEHYDROPEROXIDE	80-15-9
27232	242 LOCTITE THREADLOCKER BLUE 242 REMOVABLE	SACCHARIN	81-07-2
23085	28C1; COMPOSITE PINHOLE FILLER	TRIMETHYLBENZENE, 1,2,4-	95-63-6
109104	295 246 THREADLOCKER MEDIUM STRENGTH	CUMENE	98-82-8
109104	295 246 THREADLOCKER MEDIUM STRENGTH	CUMENEHYDROPEROXIDE	80-15-9
109104	295 246 THREADLOCKER MEDIUM STRENGTH	SACCHARIN	81-07-2
109206	3M AEROSPACE SEALANT AC-770 B-1 CATALYST	MANGANESE DIOXIDE	1313-13-9
109206	3M AEROSPACE SEALANT AC-770 B-1 CATALYST	TRIS(DIMETHYLCARBAMODITHIOATO) IRON	14484-64-1
20064	3M EC-1458	METHYL ETHYL KETONE	78-93-3

D. AIRCRAFT ACCEPTANCE INSPECTION MAN-HOURS

The evaluation of MPRA NALCOMIS corrosion data show a large number of maintenance man-hours occur when aircraft acceptance inspections are conducted. Many of these hours were expended conducting squadron-to-squadron transfer of fleet aircraft and acceptance of new or recently overhauled aircraft from the Depot. A complete listing of the NALCOMIS MPRA acceptance man-hours are contained in Appendix E.

Real time NALCOMIS corrosion treatment/prevention man-hour data was collected by aircraft utilizing the work unit code (WUC) associated to MPRA type model series aircraft. A WUC is a one-, three-, five- or seven-digit alphanumeric number that identifies an aircraft system or part of a system where maintenance performed. For example, the WUC 04119 is corrosion control inspections. Once the data was collected, it was exported into an Excel spreadsheet where the total man-hours for the various corrosion efforts were compiled using descriptive statistics. The NALCOMIS download was for the period of January 2012 to December 2013. The complete NALCOMIS data table is in Appendix C. During 2013, there were approximately 16 EP-3, 130 P-3, and 24 P-8A aircraft in fleet inventory. In October 2013, the P-8A aircraft corrosion man-hours spiked to 208 man-hours for 24 aircraft, while the P-3 corrosion man-hours increased slightly to 746 man-hours for 160 aircraft. One suspected factor was aircraft acceptance inspections. The aircraft acceptance data extracted by type equipment code is associated with each MPRA type model series.

OOMA aircraft acceptance data was entered into Excel to generate a graph illustrating just how much time and human resources squadron maintenance departments devoted to conducting aircraft acceptance inspections from January 3, 2012 to December 30, 2013.

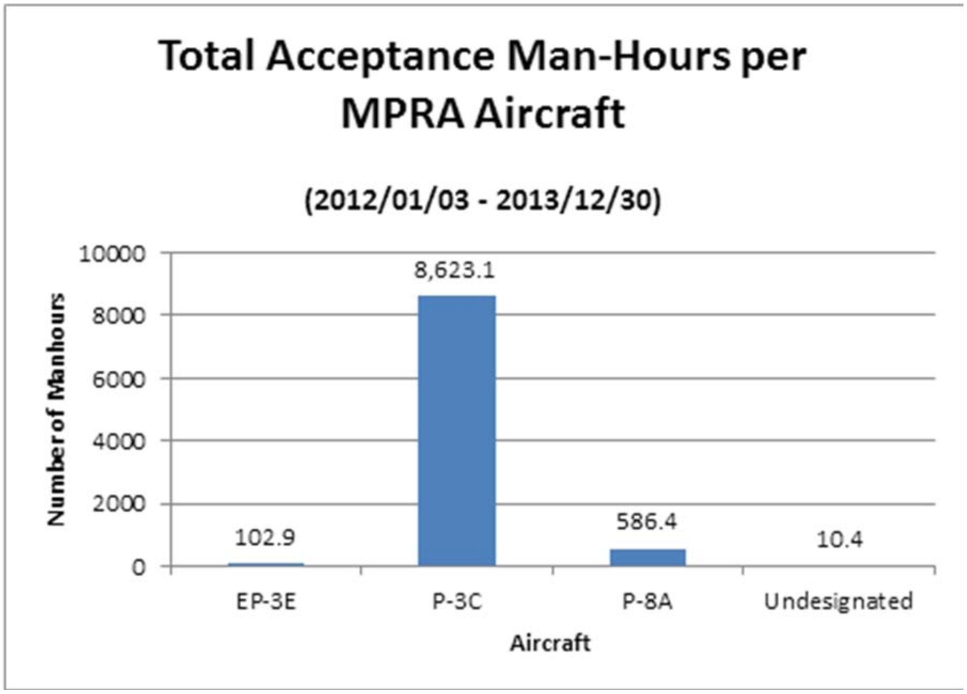
Table 2 illustrates that 23.4% of non-available fly days were contributed to corrosion. This fact has an impact on aircraft readiness/cost and warrants further study.

Table 2. P-3 Corrosion Impact on Total Non-available Days (FY2009). Source: Herzberg et al. (2011, 3–14).

TMS	**Description**	**NMC days**	**UNA days**	**Total non-available days**	**Non-available days related to corrosion**	**Percentage of Non-available days related to corrosion**
P-3	Long-range, anti-submarine warfare patrol aircraft	11,858	23,426	35,284	8,263	23.4%

Table 3 is raw OOMA MPRA acceptance data illustrating just how much time and human resources squadron maintenance departments devote to conducting aircraft acceptance inspections per aircraft, as analyzed by Wilson and Ball in 2014 from data residing in NALCOMIS. It also illustrates that a large number of maintenance man-hours are being incurred conducting aircraft acceptance inspections. These hours were expended conducting a squadron-to-squadron transfer of new P-8A and squadron-to-squadron transfers and aircraft going to and from depots.

Table 3. MPRA Acceptance Man-Hours



E. MPRA CORROSION MAN-HOURS

Table 4 contains monthly MPRA NALCOMIS statistical data roll up of MPRA raw corrosion control related man-hours entered into Excel to illustrate the level of corrosion control effort per aircraft type by month. It was re-formatted to support any present and follow-on data analysis formats.

Table 4. Monthly MPRA Corrosion Man-Hour Data NALCOMIS. Source: Wilson and Goad (2014).

	TEC: APBD	TEC: APBK	TEC: APGA
Comp Year Month	**P-C3 Man-Hours**	**EP-3E Man-Hours**	**P-8A Man-Hours**
Jan-2012	725.6	17.8	2
Feb-2012	930.2	0	7.9
Mar-2012	826.5	52.4	4.3
Apr-2012	905.3	83.2	5.2
May-2012	539.7	51.9	0.5
Jun-2012	560.3	113.2	5
Jul-2012	470.3	82.1	2.6
Aug-2012	683.1	33.8	18.2
Sep-2012	438.1	9.2	39.8
Oct-2012	570.1	12.2	3.3
Nov-2012	1,023.8	13.8	11.7
Dec-2012	435.9	4	13.2
Jan-2013	643.2	41.4	26.8
Feb-2013	615.8	15.2	19.3
Mar-2013	575.7	17.5	19.1
Apr-2013	655.1	3.4	25.9
May-2013	995.7	13.3	44.2
Jun-2013	473.4	77.7	27
Jul-2013	473.2	14.5	20.7
Aug-2013	296.3	10.9	23.6
Sep-2013	553.9	0.9	40.3
Oct-2013	746	1.3	208
Nov-2013	611.3	0	52.3
Dec-2013	531.1	28.9	61.3

The SE methods were applied to analyze existing DOD and GAO corrosion studies to NALCOMIS OOMA raw MPRA maintenance corrosion man-hour data, which were analyzed and graphed using Excel. The statistics was calculated using the solver function of the Excel add-on.

Figure 9 illustrates the delicate line of balance between corrosion correction and preventive cost. If too much corrosion prevention is performed, it could result in high labor hours and a reduction in the number of aircraft available for tasking. Too little corrective maintenance actions could cause an overall negative impact on airworthiness. The relationship between corrosion prevention and treatment cost almost seem to be inversed. The more funds dedicated to one, the fewer remain for the other. However, one other constraint must be considered, and it is readiness. Therefore, a balanced optimized approach seems to be the most desirable. The MPRA preventative corrosion man-hours for January 2012 through December 2013 were 120,000. The corrective man-hours for MPRA corrosion for the same period are approximately 13,333 man-hours. As illustrated in Figure 9, a more optimumal solution is to reduce corrosion prevention hours in areas the data supports, thus balancing the preventative vs. corrective costs. For example, the 120,000 preventative corrosion man-hours are represented on the plot as the green triangle. The 13,333 treatment corrosion man-hours are plotted as the red triangle. The blue oval represents an optimumal solution. Therefore, decreases along the preventative cost curve saves funding, while increases along the corrective cost curve can cause increased spending.

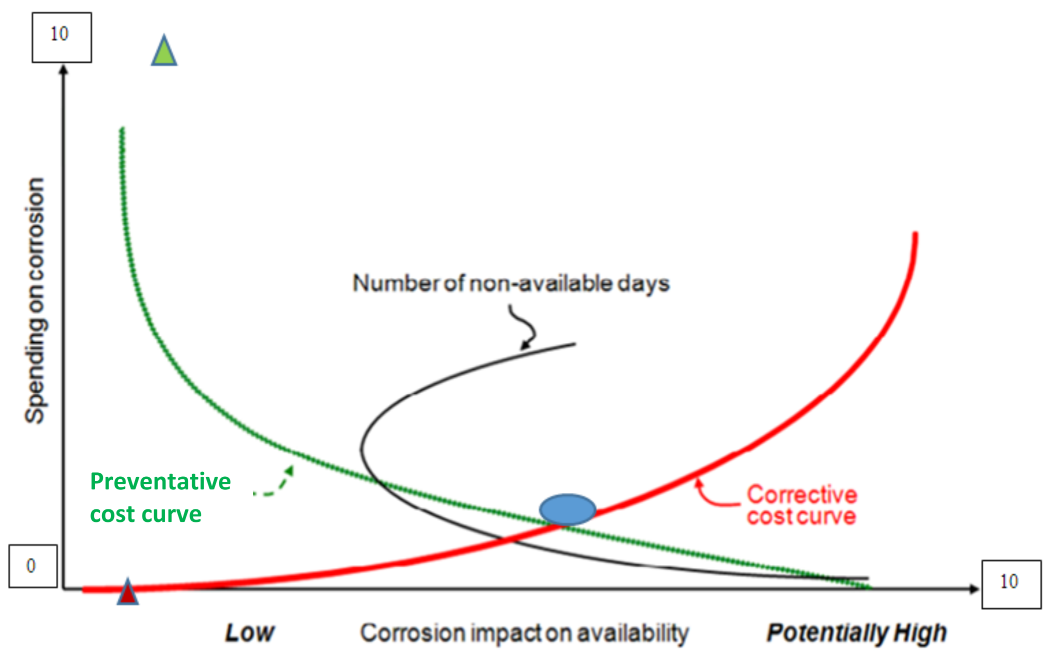


Figure 9. Adapted from Herzberg Preventative vs. Corrective Cost Curve. Adapted from Herzberg et al. (2011, 1–5).

Figure 10 exemplifies the total corrosion man-hours across all MPRA-type model series aircraft. As expected, the aging P-3C has the highest number of corrosion man-hours. However, it appears that corrosion activities are trending downward. EP-3E and P-

8 are fairly stable with P-8A having a significant spike increase from September 2013 to November 2013 cause unknown.

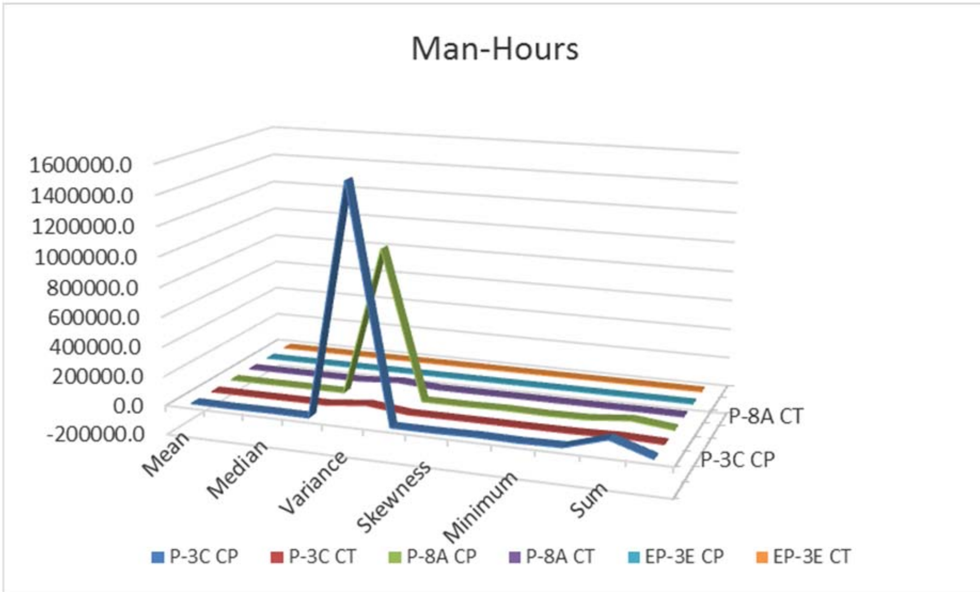


Figure 10. Analyses of MPRA Corrosion Man-Hours from NALCOMIS

Figure 11 is a comparison of corrosion prevention to corrosion treatment man-hours across MPRA by Type Model Series (TMS) from data analyzed by Wilson and Ball in 2014. It clearly illustrates that across all MPRA TMS, more man-hours are being consumed on corrosion prevention than treatment.

NALCOMIS documented corrosion actions for MPRA via download from November 1, 2012 to December 12, 2013.

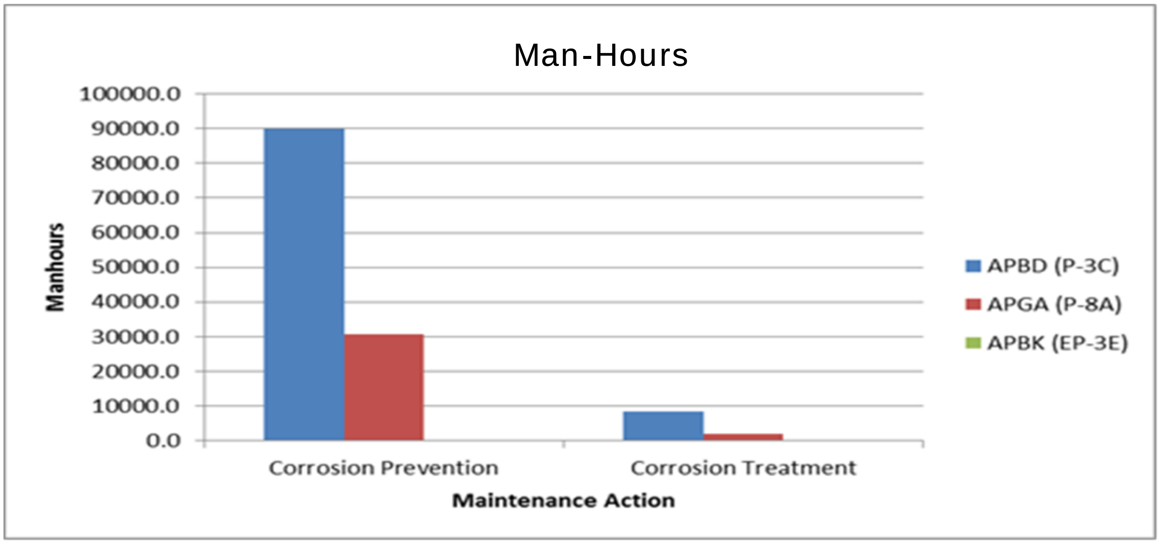


Figure 11. Analysis of MPRA Corrosion Prevention vs. Treatment Man-Hours. Adapted from Wilson and Ball (2014).

Table 5 contains the formula used in the descriptive statistics methodology from data analysis done by Wilson and Ball in 2014. The complete data file is contained in Appendix C. MPRA corrosion prevention man-hours for the time period of this research (one year) were 120,000. The larger the preventative man-hour, the less time the aircraft is available for tasking. To determine the scope and cost of 120,000 corrosion man-hours, a few assumptions had to be made. The first assumption is that the average rank of a corrosion team member would be E-5. In according to the FY 15 DOD military composite standard pay and reimbursement rates, the burdened rate for a United States Navy (USN) E-5 is $82,120 per annum. The next assumption was that a sailor worked on average five days a week, 10 hours a day. Therefore, 50 hours per week multiplied by 52 weeks came to approximately 2,600 hours per year; $82,120 divided by 2,600 hours yields an hourly rate of $31.59. The hourly rate of $31.59 multiplied by the 120,000 corrosion prevention man-hours results in $3,790,154 labor cost that year alone to prevent corrosion.

Table 5. Descriptive Statistics Applied to NALCOMIS Data to Calculate P-8A, P-3 and EP-3 Corrosion Treatment and Prevention Man-Hours.

Type Equipment Code (TEC)	Prevention/Treatment/ Total	Formula	Man-Hours
APBD	Prevention	=SUM(D4:D33)	90,075.2
APBD	Treatment	=SUM(D34:D63)	8,430.6
APBD	Total	=SUM(E4:E63)	98,505.8
APGA	Prevention	=SUM(D64:D93)	30,719.1
APGA	Treatment	=SUM(D94:D123)	1,872.9
APGA	Total	=SUM(E64:E123)	32,592.0
APBK	Prevention	=SUM(D124:D153)	281.8
APBK	Treatment	=SUM(D154:D183)	102.6
APBK	Total	=SUM(E124:E183)	384.4

Table 6 also shows that cost is not the only negative factor to high corrosion prevention man-hours. The aircraft non-availability to tasking while undergoing preventative maintenance is a major constraint to mission readiness.

Table 6. MPRA Preventative Total Non-available Days. Source: Herzberg et al. (2011, vi).

Corrosion prevention activity	Number of prevention-related non-available days	Percentage of total prevention-related non-available days
Inspect/test	45,736	71.9%
Clean	10,759	16.9%
Treat	4,074	6.4%
Preserve	1,828	2.9%
All preventive activities	63,605	100.0%

F. SUMMARY

Four main areas of findings hold the most promise for corrosion cost reductions aircraft wash intervals, aircraft painting, HMAUL, and aircraft acceptance inspections. The first finding is that an increase in aircraft wash intervals provides a two-pronged cost and schedule improvement. Increased intervals will reduce maintenance man-hours and increase aircraft availability. The aircraft wash study conducted by Abbott, Columbus, and Beale (2009) has provided data via a very successful series of sensor P-3 flight tests. This data demonstrated cost savings between the current 28-day and a prospective

112-day aircraft wash and paint extension intervals. Additional sensor response data to support an increase to the aircraft wash interval is contained in Appendix D.

This study consisted of a literature review of 117 published corrosion studies and down selected to eight for this research. The heuristic visual block diagram model, statistical data correlation of NALCOMIS MPRA corrosion data, as well as an alternate solutions evaluation for reduction and savings in aircraft wash and paint costs, were all used to conduct this research.

Pate (2008) found that the MPRA wash cycle extension would have little or no effect on aircraft corrosion. This extension would mean fewer aircraft wash labor hours, expended materials, and an increase in the aircraft readiness.

A particularly interesting corrosion study was conducted using operational Navy P-3 aircraft. It provided results through a “very extensive series of sensor samplings and flight tests. The results provided a technical basis for wash interval increases with little or no risk of increased corrosion. While it appears that the interval was increased significantly there was no apparent increase in corrosion risk” (Abbott, Columbus, and Beals 2009, 1–2).

Abbott and Kinzie (2007) found in the “Effects of Wash Rinse Intervals on Corrosion: Early Results of a Ground Based Study” that these studies provide the concise interpretations of the facts as presented. The P-3 Wash Rinse Interval Study test program had a very successful series of sensor flight tests on the P-3 aircraft. Finally, the conclusions from the additional data are the same as those reached in the final report for P-3. No significant difference appears to occur in the advancement of corrosion from wash intervals between 28 and 112 days. These conclusions provide a firm basis for the extension of wash intervals fleet-wide, and possibly, in other platforms. A recognized economic and mission effectiveness need does exist to optimize, and possibly extend, wash intervals on military aircraft, which include direct costs, labor savings, and an increase in aircraft availability.

Abbott, Columbus, and Beals (2009) in “A Study of Wash Intervals on Navy P3 Aircraft Using Corrosion Sensors,” at the time of data collection from the P-3 aircraft participating in this program, one aircraft was forward deployed in an area where it could not be easily washed. The aircraft was granted an exemption and operated under a 112-day wash interval. In this regard, the data are of particular interest. All sensors were in good condition, and all measured successfully.

Abbott and Kinzie (2006), Abbott and Kinzie (2007), and Abbott, Columbus, and Beals (2009) all came to the same generalized decision that there was sufficient trade space to extend the present scheduling of aircraft wash cycles to 112 days, as well as some corrosion treatment schedules. The results were that the aircraft wash schedules could be extended without high risk of additional corrosion damage.

MPRA corrosion prevention man-hours are as high as 120, 000. The 9 to 1 ratio of MPRA prevention corrosion man-hours to treatment man-hours is inefficient. The higher the spending on corrosion prevention, the lower the amount is spent on corrosion treatment. The “amount of preventive spending will drive the resultant corrective actions” (Herzberg et al. 2008, 1–6).

MPRA corrosion prevention and treatment man-hours combine for a total corrosion effort of 131,484 maintenance man-hours. This number represents a very large and expensive effort to combat corrosion in MPRA and efficiencies are required.

The next chapter provides conclusions and recommendations based on results from the case study review, including findings related to savings associated with MPRA wash cycles, painting, and HMAUL and acceptance inspection man-hours.

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IV. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

MPRA corrosion treatment and prevention is costly in manpower and resources, is a readiness degrader, and diverts funding that could be used for future programs and improvements. Corrosion treatments and prevention of the past will not be environmentally acceptable in the present and future.

The key to a successful corrosion strategy is a balanced comprehensive corrosion plan integrated throughout all acquisition phases. The primary question is how to integrate an ownership role for SE early in program corrosion prevention, control, and planning. Early involvement is critical in design decisions, sustainment planning, and technical evaluation of performance. The evaluation of corrosion susceptibility should be a factor in determining total system performance.

The Comptroller General estimated “that the annual cost of corrosion for DOD facilities, infrastructure, and equipment at between $9 billion and $20 billion annually” (Comptroller General of the United States 2009). To put this number in perspective, the USN could procure one USS *Gerald R. Ford* (CVN-78) annually at the expected cost of $12.9 billion dollars (Congressional Research Service 2016).

Costs can be reduced in the area of aircraft wash and paint interval extensions. Numerous man-hours are expended on organizational maintenance aircraft washing and painting aircraft, which is not only costly in dollars and man-hours, but has potential health and safety issues. Data indicates that a real possibility exists to extend MPRA paint intervals two years, and potentially more without greatly increasing the risk of additional corrosion (Forman et al. 2008) and aircraft wash intervals from 28 days to 112 days (Abbott, Columbus, and Beals 2009, 15).

In addition to aircraft wash intervals and aircraft painting timelines, storing, procuring, and disposing excessive HMAUL items are costly. The P-8A HMAUL contains large quantities of hazardous materials used in support of aircraft paint and corrosion maintenance. Numerous military facilities are currently facing billions of dollars in environmental cleanup cost. The goal should not only be to reduce HMAUL cost, but also improve the environmental imprint by reducing the amounts and toxicity of hazardous material authorized for usage. Maintaining small quantities of necessary hazardous materials is consistent in complying with existing environmental policies. This action will reduce the risk of accidental exposure to naval personnel and to the environment.

The costs associated with MPRA acceptance inspection man-hours are significant. During the period of January 3, 2013, through December 30, 2013, the MPRA community expended 9,322.8 maintenance man-hours conducting acceptance inspections alone. The aircraft acceptance hours were expended conducting a squadron-to-squadron transfer of fleet aircraft and acceptance of new or recently overhauled aircraft.

Additionally, this inspection requires the removal of sealed aircraft panels. These seals prevent water/salt and petroleum intrusions and are easily scratched and damaged conducting the inspection. Conducting a joint acceptance inspection prior to aircraft transfer would mean that when the aircraft arrives at the squadron, it is immediately ready for tasking with its corrosion preventing outer paint barrier intact.

B. RECOMMENDATIONS

The following recommendations are made for reducing HAZMAT material reductions, an aircraft paint/corrosion man-hour reduction study, an international naval corrosion working group feasibility study, and a MPRA wash intervals optimization study.

1. HAZMAT Material Reductions

Reduce the current MPRA squadron’s environmental footprint by reducing the volume and quantity of hazardous material kept on hand for organizational maintenance aircraft corrosion and paint activities. In adjunct, a continuing evaluation of less toxic but effective materials, which are suitable substitutes, must be a priority. Procurement, storage, and disposal cost reductions will result from the removal and reduction in the volume of HMAUL and associated aircraft paint chemicals. Leadership will need to evaluate existing policies and contracts, but it could create a degree of capital revitalization opportunities for the MPRA corrosion program and remain within acceptable risk tolerances. The results of these findings could put the MPRA Navy on the path to improved readiness and efficiency. The intended use of these results is also to reduce the MPRA program total life cycle corrosion costs through applying SE rigor and analysis with logistics corrosion knowledge and management experience.

2. Aircraft Paint/Corrosion Man-Hour Reduction Study

The MPRA community may be more environmentally friendly with the tiger teams doing all the corrosion/aircraft paintwork, which would allow a reduction in squadron HAZMAT, and monitor storage and use requirements. Training and organizational maintenance man-hours associated with corrosion and aircraft painting would also result in savings. Tiger team members should consist of corrosion, treatment, and paint subject matter experts who will work closely with the FST, NADEP and OEM to provide an engineering report of findings. If paint and corrosion tiger teams are adapted, the result is a reduction in inventory of squadron HMAUL and paint lockers. This action would result in less hazardous material being shipped, stored, and deployed. A reduction in procurement costs, storage, training, and disposal costs would also result. In addition, the risk to squadron personnel and the environment would decrease.

3. International Naval Corrosion Working Group Feasibility Study

Navy components worldwide face the same environmental challenges as those in the United States. The establishment of an International Naval Warfare Corrosion Group (INWCG) is another approach to identify more solutions. Members could pool collective national, commercial, and military resources to seek collaborative solutions. The group could establish cooperative programs or foreign military sales cases where participants pay monetary membership fees and for those members capable and desiring could provide chemists, engineers, logistics, or laboratory support. The charter could discuss funding, membership, and data rights in detail. The goal of the group would be to reduce the total ownership cost of corrosion across member forces collectively.

4. MPRA Wash Intervals Optimization Study

The MPRA community might be able to extend its current 28-day wash cycle to as many as 112 days with no additional significant risk for corrosion. Additional research is necessary to optimize each MPRA type model series aircraft wash cycle. The results, however, can greatly improve aircraft availability and reduce maintenance man-hours costs.

APPENDIX A. PERSONNEL EXPOSURE TO TOXIC PAINT AND CORROSION TREATMENT CHEMICALS

The following information was purposely extracted from *DOD Report No. 97-181, U.S. Navy Aircraft Corrosion Prevention and Control Program* and *NAVAIR 01-1A-509-1, Cleaning and Corrosion Control Manual.* No human subject research was conducted constructing this thesis. Therefore, the source is quoted exactly to ensure the accurate testimony contained in DOD Report 97-181 does not become corrupted. It is important to analyze and evaluate real-world examples of dangers to personnel with regard to exposure to toxic paint and corrosion treatment chemicals to search for improvements. *NAVAIR 01-1A-509-1* specifies the basic safety equipment and procedures for naval personnel in the use and handling of polyurethane paint. Polyurethane paint (isocyanate) is the primary coating used on Navy aircraft. The material requires special precautions during mixing, applying, and drying because of the toxic vapors produced. “Isocyanates released during painting operations can irate eyes, cause skin irritations, breathing difficulties in very small amounts.” Many times personnel are unaware that they are being exposed to the vapors and mists produced during spray application. Exposure is often characterized by initial respiratory discomfort, which can quickly progress into distress. After initial exposure, many workers cannot tolerate even small amounts of isocyanates. *NAVAIR 01-1A-509-1* states:

> all personnel assigned to duties involving the mixing and applying of polyurethane paint is to receive a baseline medical evaluation followed by periodic medical surveillance examinations, if recommended by an industrial hygiene survey report. The purpose of the survey report is to assess the status of occupational health hazards in the workplace. Personnel applying polyurethane paint must wear protective clothing, including chemical or splash proof goggles, coveralls, gloves, and a respirator.

The National Occupational Health and Safety Centers for Disease Control and Prevention, National Institute for Occupational Safety, International Agency for Research on Cancer and the World Health Organization all conclude that isocyanate can trigger asthma occurrences and is enumerated as a potential human carcinogen.

The difficulty in documenting exposure to isocyanate is that the fumes are both odorless and tasteless. Personnel will become ill without suspecting isocyanate as the cause. If they do seek medical attention, practitioners as well patients suspect the cause to be other illnesses.

The following examples are from real hazard reports and complaints. Naval Aviation Hazard Report “from May 1996 detailed a possible allergic reaction to isocyanate occurring at NAS Barbers Point, Hawaii. A maintenance technician was mixing polyurethane paint. Although he was wearing protective gear, such as a respirator, gloves, goggles, and a paint suit, his eyes became irritated and he had difficulty breathing.” The report stated:

> that the young sailor did not feel bad enough to stop working. He finished mixing the paint and began assisting others around the aircraft. Approximately two-three hours later, his breathing became more difficult, and he felt nauseous. His supervisor directed him to report to the medical clinic but he remained in the shop spaces until the end of his shift two hours later. At the end of his shift, the person returned to the barracks. Approximately, six hours later, the person telephoned the squadron stating that his breathing was difficult, he was nauseous, and his face and eyes badly swollen. The individual dispatched to the hospital at which they diagnosed him as having a possible allergic reaction to isocyanate. Further investigation revealed that the person was issued an improper respirator, which did not protect him from the isocyanate in the polyurethane paint.

> A complaint dated September 25, 1995, at NAS Oceana:

> stated that maintenance personnel were continuously ordered to sand and paint aircraft while other maintenance personnel were performing maintenance tasks on the same aircraft. Unprotected personnel become exposed to paint dust, epoxy polyamide paint mist, strontium chromates, thinners, and polyurethane paint. The complaint stated that immediately after an aircraft was completely painted with polyurethane, unprotected personnel were within the 40-foot safety zone of a freshly painted aircraft, which resulted in personnel being unnecessarily exposed to isocyanate vapors. In a similar complaint at NAS Oceana, dated April 5, 1996, the individual was reluctant to report the safety concerns to the squadron supervisors because of the belief that no action was going to be taken to correct the problem.

Not only is aircraft painting in Navy maintenance hangars restricted because of the potential health effects to personnel, but also because painting in maintenance hangars is a potential fire hazard. The principal fire hazard of spray painting in the aircraft hangars comes from flammable liquids and their vapors, and from highly combustible residues that are deposited in the area. Either on ship or shore, a fire is a very serious emergency, which could result in significant loss of life, valuable assets, facilities, and equipment (Office of the Inspector General 1997, 6).

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APPENDIX B. P-8A AIRCRAFT HAZARDOUS MATERIAL AUTHORIZED USE LIST (HMAUL) RESTRICTED MATERIALS

This table shows the complete P-8A HMAUL table (U.S. Navy 2013).

MSDS#	Product Name	Restricted Component	CAS#
23278	10C32; LAMINAR X-500 HARDENER	ETHYL BENZENE	100-41-4
23278	10C32; LAMINAR X-500 HARDENER	TOLUENE DIISOCYANATE	26471-62-5
23278	10C32; LAMINAR X-500 HARDENER	XYLENE	1330-20-7
88944	10P20-44; HIGH SOLIDS EPOXY PRIMER	ETHYL BENZENE	100-41-4
88944	10P20-44; HIGH SOLIDS EPOXY PRIMER	METHYL ISOBUTYL KETONE	108-10-1
88944	10P20-44; HIGH SOLIDS EPOXY PRIMER	STRONTIUM CHROMATE	7789-06-2
88944	10P20-44; HIGH SOLIDS EPOXY PRIMER	XYLENE	1330-20-7
75947	1311 KRYLON MATTE FINISH SPRAY COATING	TOLUENE	108-88-3
95283	15-71-2-51083	METHYL ETHYL KETONE	78-93-3
95283	15-71-2-51083	TOLUENE	108-88-3
88552	192 LOCTITE 7471 PRIMER T 19268	MERCAPTOBENZOTHIAZOLE	149-30-4
110910	214 LOCTITE 222 THREADLOCKER LOW STRENGTH 21465	CUMENEHYDROPEROXIDE	80-15-9
110910	214 LOCTITE 222 THREADLOCKER LOW STRENGTH 21465	SACCHARIN	81-07-2
27232	242 LOCTITE THREADLOCKER BLUE 242 REMOVABLE	CUMENEHYDROPEROXIDE	80-15-9
27232	242 LOCTITE THREADLOCKER BLUE 242 REMOVABLE	SACCHARIN	81-07-2
23085	28C1; COMPOSITE PINHOLE FILLER	TRIMETHYLBENZENE, 1,2,4-	95-63-6
109104	295 246 THREADLOCKER MEDIUM STRENGTH	CUMENE	98-82-8
109104	295 246 THREADLOCKER MEDIUM STRENGTH	CUMENEHYDROPEROXIDE	80-15-9
109104	295 246 THREADLOCKER MEDIUM STRENGTH	SACCHARIN	81-07-2
109206	3M AEROSPACE SEALANT AC-770 B-1 CATALYST	MANGANESE DIOXIDE	1313-13-9
109206	3M AEROSPACE SEALANT AC-770 B-1 CATALYST	TRIS(DIMETHYLCARBAMODITHIOATO) IRON	14484-64-1
20064	3M EC-1458	METHYL ETHYL KETONE	78-93-3
20064	3M EC-1458	PHENOL	108-95-2
23799	3M SCOTCH-WELD INDUSTRIAL ADHESIVE EC-1870, TAN	HEXANE	110-54-3
23799	3M SCOTCH-WELD INDUSTRIAL ADHESIVE EC-1870, TAN	RESIN ACIDS AND ROSIN ACIDS, CALCIUM ZINC SALTS	68334-35-0
49617	3M SCOTCH-WELD NEO HIGH PERFORMANCE RUBBER & GASKET 1300L	CYCLOHEXANE	110-82-7
49617	3M SCOTCH-WELD NEO HIGH PERFORMANCE RUBBER & GASKET 1300L	HEXANE	110-54-3
49617	3M SCOTCH-WELD NEO HIGH PERFORMANCE RUBBER & GASKET 1300L	METHYL ETHYL KETONE	78-93-3
49617	3M SCOTCH-WELD NEO HIGH	TOLUENE	108-88-3

MSDS#	Product Name	Restricted Component	CAS#
	PERFORMANCE RUBBER & GASKET 1300L		
49617	3M SCOTCH-WELD NEO HIGH PERFORMANCE RUBBER & GASKET 1300L	ZINC OXIDE	1314-13-2
29190	3M SCOTCH-WELD TAMPER PROOF SEALANT 1252, WHITE	METHYL ETHYL KETONE	78-93-3
29190	3M SCOTCH-WELD TAMPER PROOF SEALANT 1252, WHITE	ZINC OXIDE	1314-13-2
130586	3M SURFACE PRE-TREATMENT AC-131 CB PART B	METHANOL	67-56-1
82650	446-22-1000; WHITE BAC 702 715480	METHYL ETHYL KETONE	78-93-3
82650	446-22-1000; WHITE BAC 702 715480	METHYL ISOBUTYL KETONE	108-10-1
82650	446-22-1000; WHITE BAC 702 715480	TOLUENE	108-88-3
85408	454-4-1; INTEGRAL FUEL TANK COATING	ACETALDEHYDE	75-07-0
85408	454-4-1; INTEGRAL FUEL TANK COATING	BENZENE	71-43-2
85408	454-4-1; INTEGRAL FUEL TANK COATING	BUTANOL	71-36-3
85408	454-4-1; INTEGRAL FUEL TANK COATING	CADMIUM	7440-43-9
85408	454-4-1; INTEGRAL FUEL TANK COATING	CHROMIC ACID, ZINC SALT (1:1)	13530-65-9
85408	454-4-1; INTEGRAL FUEL TANK COATING	ETHYL BENZENE	100-41-4
85408	454-4-1; INTEGRAL FUEL TANK COATING	FORMALDEHYDE	50-00-0
85408	454-4-1; INTEGRAL FUEL TANK COATING	LEAD	7439-92-1
85408	454-4-1; INTEGRAL FUEL TANK COATING	METHYL ETHYL KETONE	78-93-3
85408	454-4-1; INTEGRAL FUEL TANK COATING	METHYL ISOBUTYL KETONE	108-10-1
85408	454-4-1; INTEGRAL FUEL TANK COATING	TOLUENE	108-88-3
85408	454-4-1; INTEGRAL FUEL TANK COATING	XYLENE	1330-20-7
85408	454-4-1; INTEGRAL FUEL TANK COATING	ZINC HYDROXIDE	20427-58-1
82874	512X310 BASE COMPONENT	BUTANOL	71-36-3
82874	512X310 BASE COMPONENT	METHYL ETHYL KETONE	78-93-3
82874	512X310 BASE COMPONENT	XYLENE	1330-20-7
91642	515K011 BASE COMPONENT	BUTANOL	71-36-3
91642	515K011 BASE COMPONENT	CHROMIC ACID, CALCIUM SALT (1:1)	13765-19-0
91642	515K011 BASE COMPONENT	ETHYL BENZENE	100-41-4
91642	515K011 BASE COMPONENT	METHYL ETHYL KETONE	78-93-3
91642	515K011 BASE COMPONENT	METHYL ISOBUTYL KETONE	108-10-1
91642	515K011 BASE COMPONENT	NICKEL OXIDE	1313-99-1
91642	515K011 BASE COMPONENT	TOLUENE	108-88-3
91642	515K011 BASE COMPONENT	XYLENE	1330-20-7
82939	528X306 SUPER KOROPON ANTI-STATIC RADOMECTG BASE COMPONENT	BUTANOL	71-36-3
82939	528X306 SUPER KOROPON ANTI-STATIC RADOMECTG BASE COMPONENT	METHYL ETHYL KETONE	78-93-3
81253	528X310 BASE COMPONENT	BUTANOL	71-36-3
81253	528X310 BASE COMPONENT	METHYL ETHYL KETONE	78-93-3
81253	528X310 BASE COMPONENT	METHYL ISOBUTYL KETONE	108-10-1
81253	528X310 BASE COMPONENT	XYLENE	1330-20-7
78452	823-707	BUTANOL	71-36-3
78452	823-707	METHANOL	67-56-1
78452	823-707	METHYL ETHYL KETONE	78-93-3
78452	823-707	METHYL ISOBUTYL KETONE	108-10-1

MSDS#	Product Name	Restricted Component	CAS#
78452	823-707	STRONTIUM CHROMATE	7789-06-2
78452	823-707	XYLENE	1330-20-7
84326	860 B-1/6 ACCELERATOR	MANGANESE DIOXIDE	1313-13-9
84327	860 B-1/6 BASE COMPOUND	TOLUENE	108-88-3
88862	9001W100; AERODEX 17925 WHITE	DIBUTYL PHTHALATE	84-74-2
88862	9001W100; AERODEX 17925 WHITE	METHYL-2-PYRROLIDINONE, 1-	872-50-4
81980	910-012 ACT COMP ONLY W/515K011	ETHYL BENZENE	100-41-4
81980	910-012 ACT COMP ONLY W/515K011	METHANOL	67-56-1
81980	910-012 ACT COMP ONLY W/515K011	METHYL ETHYL KETONE	78-93-3
81980	910-012 ACT COMP ONLY W/515K011	TOLUENE	108-88-3
81980	910-012 ACT COMP ONLY W/515K011	XYLENE	1330-20-7
81252	910X464 SUPER KOROPON CONDUCT/ANTI-STATIC CTG.	ETHYL BENZENE	100-41-4
81252	910X464 SUPER KOROPON CONDUCT/ANTI-STATIC CTG.	METHYL ETHYL KETONE	78-93-3
81252	910X464 SUPER KOROPON CONDUCT/ANTI-STATIC CTG.	TOLUENE	108-88-3
81252	910X464 SUPER KOROPON CONDUCT/ANTI-STATIC CTG.	XYLENE	1330-20-7
81600	910X533 ACTIVATOR COMPONENT	METHANOL	67-56-1
81600	910X533 ACTIVATOR COMPONENT	TOLUENE	108-88-3
108121	AC -360 ACCELERATOR	MANGANESE DIOXIDE	1313-13-9
108122	AC-360 CLASS B-BASE	FORMALDEHYDE	50-00-0
108122	AC-360 CLASS B-BASE	PHENOL	108-95-2
109208	AC-770 CLASS B-1 BASE	FORMALDEHYDE	50-00-0
109208	AC-770 CLASS B-1 BASE	PHENOL	108-95-2
21141	ADTECH MICRO-ULTRA 15–3	METHANOL	67-56-1
21141	ADTECH MICRO-ULTRA 15–3	STYRENE	100-42-5
82041	AERO 40	PHOSPHORODITHIOIC ACID, O,O-DI-C1-14-ALKYL ESTERS, ZINC SALT	68649-42-3
48860	AEROKROIL	BUTYL ALCOHOL, SEC-	78-92-2
48860	AEROKROIL	TRIMETHYLBENZENE, 1,2,4-	95-63-6
91406	ALODINE 1132	CHROMIUM CHROMATE	24613-89-6
22335	ALODINE1200S	CHROMIUM TRIOXIDE	1333-82-0
22335	ALODINE1200S	POTASSIUM FERRICYANIDE	13746-66-2
99400	ALODINE 600 RTU	CHROMIC ACID	7738-94-5
99400	ALODINE 600 RTU	SODIUM CHROMATE	7775-11-3
136482	ANTI SEIZE SEALING COMPOUND HIGH TEMPERATURE	LEAD	7439-92-1
52663	ARDROX 985-P14 FLUORESCENT PENETRANT PSOTEMULSIFIABLE	NAPHTHALENE	91-20-3
54841	ARDROX AV 100D	BARIUM DINONYLNAPHTHALENE SULFONATE	25619-56-1
49445	ARMITE LF AS 328 BMS 3–28A	ZINC	7440-66-6
102619	ASTROSOL ORANGE	DIETHANOLAMINE	111-42-2
102619	ASTROSOL ORANGE	DIOXANE	123-91-1
102619	ASTROSOL ORANGE	ETHYLENE OXIDE	75-21-8
102619	ASTROSOL ORANGE	METHANOL	67-56-1
20145	AVERY DENNISON 4930 SERIES SCREEN INK	BARIUM	7440-39-3
20145	AVERY DENNISON 4930 SERIES SCREEN INK	NICKEL	7440-02-0

MSDS#	Product Name	Restricted Component	CAS#
101850	AZ 634–2	AMMONIA	7664-41-7
97946	BARSOL A-2904	METHYL ETHYL KETONE	78-93-3
97946	BARSOL A-2904	TOLUENE	108-88-3
146852	BUTANOL-1	BUTANOL	71-36-3
22120	C25/90S; THINNER FOR G12E25	BENZENE	71-43-2
22120	C25/90S; THINNER FOR G12E25	METHYL ETHYL KETONE	78-93-3
22120	C25/90S; THINNER FOR G12E25	METHYL ISOBUTYL KETONE	108-10-1
91814	CA 8000/B7067X BASE COMPONENT	ETHYL BENZENE	100-41-4
91814	CA 8000/B7067X BASE COMPONENT	METHYL ISOBUTYL KETONE	108-10-1
91814	CA 8000/B7067X BASE COMPONENT	TOLUENE	108-88-3
91814	CA 8000/B7067X BASE COMPONENT	XYLENE	1330-20-7
92863	CA 8010DDESOTHANE HS ACTIVATOR ACCELERATOR COMPONENT	CUMENE	98-82-8
92863	CA 8010DDESOTHANE HS ACTIVATOR ACCELERATOR COMPONENT	ETHYL BENZENE	100-41-4
103696	CA 8022/B7022DESOTHANE HS SEMI-GLOSS WHITE	ETHYL BENZENE	100-41-4
103696	CA 8022/B7022DESOTHANE HS SEMI-GLOSS WHITE	TOLUENE	108-88-3
103696	CA 8022/B7022DESOTHANE HS SEMI-GLOSS WHITE	XYLENE	1330-20-7
113923	CA 8100/B707X ANTI-CHAFE GLOSS GRAY	METHYL ISOBUTYL KETONE	108-10-1
113923	CA 8100/B707X ANTI-CHAFE GLOSS GRAY	XYLENE	1330-20-7
116190	CA 8100B ANTI-CHAFE ACTIVATOR	HEXAMETHYLENEDIISOCYANATE	822-06-0
115673	CA 8100C THINNER COMPNT	METHYL ISOBUTYL KETONE	108-10-1
85406	CA-109 INTEGRAL FUEL TANK COATING CURE SOLUTION	BENZENE	71-43-2
85406	CA-109 INTEGRAL FUEL TANK COATING CURE SOLUTION	METHYL ETHYL KETONE	78-93-3
85406	CA-109 INTEGRAL FUEL TANK COATING CURE SOLUTION	TOLUENE	108-88-3
103695	CA8012/B701DESO HS FLAT BLACK - BASE COMPOUND	METHYL ISOBUTYL KETONE	108-10-1
103695	CA8012/B701DESO HS FLAT BLACK - BASE COMPOUND	XYLENE	1330-20-7
18161	CEE BEE B-55	HYDROFLUORIC ACID	7664-39-3
20499	CHO-BOND 4660	COPPER	7440-50-8
20499	CHO-BOND 4660	SILVER	7440-22-4
123894	CHROMIUM TRIOXIDE	CHROMIUM TRIOXIDE	1333-82-0
16395	DAPCO 1–100 PRIMER	METHYL ETHYL KETONE	78-93-3
149882	DENATURED ALCOHOL	METHANOL	67-56-1
49105	DOW CORNING 3145 RTV MIL-A-46146 ADHESIVE/SEALANT - GRAY	METHANOL	67-56-1
1985	DOW CORNING 90–006-2 SEMKIT AEROSPACE SEALANT & CATALYST	CHROMIUM (III) OXIDE (2:3)	1308-38-9
146132	DOW CORNING PR-1200 RTV PRIME COAT RED	ETHYL BENZENE	100-41-4
146132	DOW CORNING PR-1200 RTV PRIME COAT RED	TOLUENE	108-88-3
89770	EASTMAN MPK METHYL PROPYL KETONE	METHYL ISOBUTYL KETONE	108-10-1
84995	EC-105	BENZENE	71-43-2
84995	EC-105	BUTANOL	71-36-3
84995	EC-105	ETHYL BENZENE	100-41-4
84995	EC-105	METHYL ETHYL KETONE	78-93-3

MSDS#	Product Name	Restricted Component	CAS#
84995	EC-105	METHYL ISOBUTYL KETONE	108-10-1
84995	EC-105	TOLUENE	108-88-3
84995	EC-105	XYLENE	1330-20-7
88943	EC-265; HS PRIMER CURING SOLUTION	TOLUENE	108-88-3
115011	ECL-G-1622; WHITE BAC 70846 715108	ETHYL BENZENE	100-41-4
19748	EPIBOND 126 A	EPICHLOROHYDRIN	106-89-8
19748	EPIBOND 126 A	VINYL CHLORIDE	75-01-4
16420	EVERLUBE 620 PEV620	METHANOL	67-56-1
16420	EVERLUBE 620 PEV620	PHENOL	108-95-2
16420	EVERLUBE 620 PEV620	TOLUENE	108-88-3
39512	FL-20 PRIMER	METHYLENE DIPHENYLDIISOCYANATE	101-68-8
28562	FLEXANE 80 LIQUID RESIN	CYCLOHEXANE, 1,1'-METHYLENEBIS(4-ISOCYANATO-	5124-30-1
56518	H99BY4	ETHYL BENZENE	100-41-4
56518	H99BY4	METHYL ETHYL KETONE	78-93-3
56518	H99BY4	TOLUENE	108-88-3
18532	HETRON 92 RESIN	STYRENE	100-42-5
148952	INSTABOND 146 ANAEROBIC SEALING COMPOUND TYPE I, GRADE K	CUMENEHYDROPEROXIDE	80-15-9
148952	INSTABOND 146 ANAEROBIC SEALING COMPOUND TYPE I, GRADE K	METHYL ACRYLATE	96-33-3
146738	INSTABOND 410 ANAEROBIC SEALING COMPOUND	CUMENEHYDROPEROXIDE	80-15-9
146738	INSTABOND 410 ANAEROBIC SEALING COMPOUND	METHYL ACRYLATE	96-33-3
146738	INSTABOND 410 ANAEROBIC SEALING COMPOUND	SACCHARIN	81-07-2
20684	L4145-14H	METHYL ETHYL KETONE	78-93-3
29001	LUBRIPLATE 630-A	ZINC OXIDE	1314-13-2
119546	LYSOL	PHENYLPHENOL, 2-	90-43-7
133873	MASTINOX6856K JOINTING COMPOUND	BARIUM CHROMATE	10294-40-3
133873	MASTINOX6856K JOINTING COMPOUND	ETHYL BENZENE	100-41-4
133873	MASTINOX6856K JOINTING COMPOUND	STRONTIUM CHROMATE	7789-06-2
133873	MASTINOX6856K JOINTING COMPOUND	TOLUENE	108-88-3
133873	MASTINOX6856K JOINTING COMPOUND	XYLENE	1330-20-7
148059	METHYL ISOBUTYL KETONE	METHYL ISOBUTYL KETONE	108-10-1
105034	MIL-P-15328B/MIL-C-8514A PART A	BUTANOL	71-36-3
105034	MIL-P-15328B/MIL-C-8514A PART A	CHROMIC ACID, ZINC SALT (1:1)	13530-65-9
105034	MIL-P-15328B/MIL-C-8514A PART A	CHROMIUM	7440-47-3
105034	MIL-P-15328B/MIL-C-8514A PART A	METHANOL	67-56-1
105035	MIL-P-15328B/MIL-C-8514A PART B	METHANOL	67-56-1
145546	MN 2	FORMALDEHYDE	50-00-0
17011	MOBIL JET OIL II	DIPHENYLAMINE	122-39-4
56406	MOLYKOTE 321 DRY FILM LUBRICANT	NITRO-1,3-BENZENEDICARBOXYLIC ACID, 5-, ZINC SALT (1:1)	60580-61-2
49117	MOLYKOTE G-N METAL ASSEMBLY PASTE	DIPHOSPHORIC ACID, ZINC SALT (1:2)	7446-26-6
61785	NEVER-SEEZ PURE NICKEL SPECIAL	NICKEL	7440-02-0
86113	NITRIC ACID	NITRIC ACID	7697-37-2
92002	PC-233; CURING SOLUTION	HEXAMETHYLENEDIISOCYANATE	822-06-0

MSDS#	Product Name	Restricted Component	CAS#
86907	PEROXIDE CREAM HARDENER	BENZOYL PEROXIDE	94-36-0
84585	PR 1197 PART B	BUTYLENE GLYCOL PMR W/ 2,4-TOLUENEDIISOCYANATE	9050-83-3
84585	PR 1197 PART B	METHYL ETHYL KETONE	78-93-3
84585	PR 1197 PART B	TOLUENE DIISOCYANATE	26471-62-5
87070	PR 1428 B 2 PART A	MANGANESE DIOXIDE	1313-13-9
87071	PR 1428 B 2 PART B	NAPHTHALENESULFONIC ACID, HYDROXYNAPTHTALENYLAZO, BARIUM SAL	1103-38-4
87071	PR 1428 B 2 PART B	THIRAM	137-26-8
62573	PR-1405G, PART A ACCELERATOR COMPONENT	MAGNESIUM CHROMATE	13423-61-5
62573	PR-1405G, PART A ACCELERATOR COMPONENT	MANGANESE DIOXIDE	1313-13-9
62574	PR-1405G, PART B BASE COMPONENT	METHYL ETHYL KETONE	78-93-3
62574	PR-1405G, PART B BASE COMPONENT	TOLUENE	108-88-3
86301	PR-1440 A-1/2, PART A ACCELERATOR COMPONENT	MANGANESE DIOXIDE	1313-13-9
86302	PR-1440 A-1/2, PART B BASE COMPONENT	METHYL ETHYL KETONE	78-93-3
86302	PR-1440 A-1/2, PART B BASE COMPONENT	TOLUENE	108-88-3
82104	PR-1440 A-2, PART A ACCELERATOR COMPONENT	MANGANESE DIOXIDE	1313-13-9
88541	PR-1440 A-2, PART B BASE COMPOUND	BENZENE	71-43-2
88541	PR-1440 A-2, PART B BASE COMPOUND	METHYL ETHYL KETONE	78-93-3
88541	PR-1440 A-2, PART B BASE COMPOUND	TOLUENE	108-88-3
82049	PR-148 ADHESION PROMOTER	METHYL ETHYL KETONE	78-93-3
82049	PR-148 ADHESION PROMOTER	TOLUENE	108-88-3
139344	PR-1772 B-1, PART A ACCELERATOR COMPONENT	ACRYLONITRILE	107-13-1
139344	PR-1772 B-1, PART A ACCELERATOR COMPONENT	MANGANESE DIOXIDE	1313-13-9
84584	PR1197 PART A	METHYL ETHYL KETONE	78-93-3
80809	PRO-SEAL 870 B-1/2, PART A - ACCELERATOR COMPONENT	MAGNESIUM CHROMATE	13423-61-5
80809	PRO-SEAL 870 B-1/2, PART A - ACCELERATOR COMPONENT	MANGANESE DIOXIDE	1313-13-9
80810	PRO-SEAL 870 B-1/2, PART B - BASE COMPONENT	BENZENE	71-43-2
80810	PRO-SEAL 870 B-1/2, PART B - BASE COMPONENT	FORMALDEHYDE	50-00-0
80810	PRO-SEAL 870 B-1/2, PART B - BASE COMPONENT	PHENOL	108-95-2
80810	PRO-SEAL 870 B-1/2, PART B - BASE COMPONENT	THIRAM	137-26-8
80810	PRO-SEAL 870 B-1/2, PART B - BASE COMPONENT	TOLUENE	108-88-3
57800	PRO-SEAL 890 A-2 (MIXED & FROZEN) ONE COMPONENT	MANGANESE DIOXIDE	1313-13-9
57800	PRO-SEAL 890 A-2 (MIXED & FROZEN) ONE COMPONENT	METHYL ETHYL KETONE	78-93-3
57800	PRO-SEAL 890 A-2 (MIXED & FROZEN) ONE COMPONENT	TOLUENE	108-88-3
88850	PRO-SEAL 890 B-1/2, PART A ACCELERATOR COMPONENT	MANGANESE DIOXIDE	1313-13-9
86692	PRO-SEAL 890 B-1/2, PART B BASE COMPONENT	THIRAM	137-26-8
86692	PRO-SEAL 890 B-1/2, PART B BASE COMPONENT	TOLUENE	108-88-3
90678	PRO-SEAL 890 B-2, PART A	MANGANESE DIOXIDE	1313-13-9

MSDS#	Product Name	Restricted Component	CAS#
	ACCELERATOR COMPONENT		
83546	PRO-SEAL 890 B-2, PART B BASE COMPONENT	BENZENE	71-43-2
83546	PRO-SEAL 890 B-2, PART B BASE COMPONENT	THIRAM	137-26-8
83546	PRO-SEAL 890 B-2, PART B BASE COMPONENT	TOLUENE	108-88-3
86821	PS 870 B 2 PART A	MAGNESIUM CHROMATE	13423-61-5
86821	PS 870 B 2 PART A	MANGANESE DIOXIDE	1313-13-9
86822	PS 870 B 2 PART B	METHYL ETHYL KETONE	
86822	PS 870 B 2 PART B	TOLUENE	108-88-3
89217	RTV6708POLYSILOXANE SEALANT (TRANSLUCENT)	TOLUENE	108-88-3
55114	SCOTCH-WELD EPOXY ADHESIVE 2216, GRAY (PART A)	TOLUENE	108-88-3
17313	SERMETEL 249	ZINC	7440-66-6
17314	SERMETEL 273	ETHYLENE GLYCOL	107-21-1
7868	SERMETEL W	CHROMIUM TRIOXIDE	1333-82-0
88506	SPRAYLAT SC-1090	METHANOL	67-56-1
16692	SS4004P SILICONE PRIMER SOLUTION	BUTANOL	71-36-3
16692	SS4004P SILICONE PRIMER SOLUTION	ETHYL BENZENE	100-41-4
16692	SS4004P SILICONE PRIMER SOLUTION	XYLENE	1330-20-7
104907	STODDARD SOLVENT	BENZENE	71-43-2
108504	SUPER WHITE MULTI-PURPOSE GREASE (NLGI GRADE 2) SL3150,	BIS(DIPENTYLCARBAMODITHIOATO)ZINC	15337-18-5
108504	SUPER WHITE MULTI-PURPOSE GREASE (NLGI GRADE 2) SL3150,	ZINC OXIDE	1314-13-2
123483	TOLUENE	TOLUENE	108-88-3
116944	TT-N-95 TYPE II ALIPHATIC NAPHTHA	TOLUENE	108-88-3
85374	TURCO 4460-BK	CYCLOHEXANE	110-82-7
85374	TURCO 4460-BK	METHYL ISOBUTYL KETONE	108-10-1
85374	TURCO 4460-BK	TOLUENE	108-88-3
32248	TURCO 5351 (T-5469)	METHYLENE CHLORIDE	75-09-2
32248	TURCO 5351 (T-5469)	PHENOL	108-95-2
32248	TURCO 5351 (T-5469)	SODIUM CHROMATE	7775-11-3
6778	TURCO JET CLEAN C	SODIUM NITRITE	7632-00-0
104230	TURCO LIQUID ARR (T-4181L)	DIETHANOLAMINE	111-42-2
61043	URALANE5774A	CYCLOHEXANE, 1,1’-METHYLENEBIS(4-ISOCYANATO-	5124-30-1
61043	URALANE5774A	DICYCLOHEXYLMETHANE-4,4’-DIISOCYANATEPREPOLYMER	67837-35-8
61043	URALANE5774A	ETHYL BENZENE	100-41-4
61043	URALANE5774A	TOLUENE	108-88-3
121537	URALANE5774C	ETHYL BENZENE	100-41-4
62032	WHITE FLAT 747–112F	METHANOL	67-56-1
83194	X-310A; POLYURETHANE CATALYST	ETHYL BENZENE	100-41-4
83194	X-310A; POLYURETHANE CATALYST	HEXAMETHYLENEDIISOCYANATE	822-06-0
83194	X-310A; POLYURETHANE CATALYST	XYLENE	1330-20-7
82649	X-530; HS EPOXY ENAMEL CURING SOLUTION	BUTANOL	71-36-3
82649	X-530; HS EPOXY ENAMEL CURING SOLUTION	TOLUENE	108-88-3

MSDS#	Product Name	Restricted Component	CAS#
79500	XYLENE	ETHYL BENZENE	100-41-4
79500	XYLENE	XYLENE	1330-20-7

Total of 273 hazardous materials items from U.S. Navy, P-8A Program 2013 “HMAUL Restricted Materials List” (Rev 16 Dec 13)

APPENDIX C. MPRA NALCOMIS CORROSION DATA

This table presents NALCOMIS MPRA corrosion prevention/treatment man-hours after analysis done by Wilson and Ball in 2014.

TEC	Type MAF Code (OOMA)	Comp Year Month	Man-Hours (Monthly)	Man-Hours (MAF)	Man-Hours (TEC)
APBD (P-3)	Corrosion Prevention	2012-06	2714.9	90075.2	98505.8
		2012-07	2203.9		
		2012-08	2120.2		
		2012-09	3490.4		
		2012-10	1341.7		
		2012-11	3620.6		
		2012-12	1546.7		
		2013-01	3371.8		
		2013-02	2193.2		
		2013-03	3654.4		
		2013-04	2740.6		
		2013-05	3110.4		
		2013-06	887.3		
		2013-07	1715.4		
		2013-08	2462.4		
		2013-09	3219.4		
		2013-10	3525.3		
		2013-11	3691.9		
		2013-12	2748.2		
		2014-01	4343.9		
		2014-02	4092.5		
		2014-03	6179.7		
		2014-04	5056.4		
		2014-05	3079.3		
		2014-06	2434.8		
		2014-07	2549.5		
		2014-08	5574.8		
		2014-09	3423.4		
		2014-10	1953.4		
		2014-11	1028.8		
	Corrosion Treatment	2012-06	142.6	8430.6	
		2012-07	195.3		
		2012-08	203.5		
		2012-09	169.0		
		2012-10	172.2		
		2012-11	817.0		
		2012-12	127.8		

TEC	Type MAF Code (OOMA)	Comp Year Month	Man-Hours (Monthly)	Man-Hours (MAF)	Man-Hours (TEC)
		2013-01	215.1		
		2013-02	222.3		
		2013-03	472.6		
		2013-04	268.6		
		2013-05	722.5		
		2013-06	114.5		
		2013-07	364.8		
		2013-08	125.7		
		2013-09	293.4		
		2013-10	242.5		
		2013-11	212.3		
		2013-12	73.3		
		2014-01	119.4		
		2014-02	217.6		
		2014-03	315.0		
		2014-04	476.2		
		2014-05	215.5		
		2014-06	505.3		
		2014-07	371.8		
		2014-08	266.3		
		2014-09	393.7		
		2014-10	238.5		
		2014-11	156.3		
APGA (P-8A)	Corrosion Prevention	2012-06	161.8	30719.1	32592.0
		2012-07	83.4		
		2012-08	69.1		
		2012-09	216.1		
		2012-10	42.1		
		2012-11	14.8		
		2012-12	31.2		
		2013-01	35.4		
		2013-02	16.4		
		2013-03	662.5		
		2013-04	754.5		
		2013-05	969.8		
		2013-06	352.4		
		2013-07	1091.7		
		2013-08	1355.2		
		2013-09	1404.3		
		2013-10	2329.5		
		2013-11	4407.7		
		2013-12	1416.9		
		2014-01	1689.6		
		2014-02	2134.7		

TEC	Type MAF Code (OOMA)	Comp Year Month	Man-Hours (Monthly)	Man-Hours (MAF)	Man-Hours (TEC)
		2014-03	1580.0		
		2014-04	742.0		
		2014-05	801.3		
		2014-06	1628.5		
		2014-07	759.2		
		2014-08	436.7		
		2014-09	1012.1		
		2014-10	1571.3		
		2014-11	2948.9		
	Corrosion Treatment	2012-06	0.0	1872.9	
		2012-07	0.0		
		2012-08	2.3		
		2012-09	0.0		
		2012-10	0.0		
		2012-11	0.0		
		2012-12	0.6		
		2013-01	17.1		
		2013-02	1.5		
		2013-03	0.0		
		2013-04	4.6		
		2013-05	6.0		
		2013-06	17.0		
		2013-07	10.1		
		2013-08	5.2		
		2013-09	28.5		
		2013-10	355.5		
		2013-11	699.6		
		2013-12	76.8		
		2014-01	21.5		
		2014-02	64.2		
		2014-03	0.0		
		2014-04	41.0		
		2014-05	120.9		
		2014-06	24.3		
		2014-07	11.6		
		2014-08	104.0		
		2014-09	25.5		
		2014-10	188.5		
		2014-11	46.6		
APBK (EP-3E)	Corrosion Prevention	2012-06	12.5	281.8	384.4
		2012-07	4.6		
		2012-08	0.0		
		2012-09	1.7		
		2012-10	0.2		

TEC	Type MAF Code (OOMA)	Comp Year Month	Man-Hours (Monthly)	Man-Hours (MAF)	Man-Hours (TEC)
		2012-11	12.9		
		2012-12	6.3		
		2013-01	6.0		
		2013-02	0.0		
		2013-03	10.0		
		2013-04	16.8		
		2013-05	1.7		
		2013-06	0.0		
		2013-07	12.5		
		2013-08	24.1		
		2013-09	14.7		
		2013-10	6.9		
		2013-11	5.1		
		2013-12	9.7		
		2014-01	5.6		
		2014-02	11.9		
		2014-03	1.4		
		2014-04	19.6		
		2014-05	28.3		
		2014-06	15.8		
		2014-07	15.7		
		2014-08	2.9		
		2014-09	19.6		
		2014-10	2.5		
		2014-11	12.8		
	Corrosion Treatment	2012-06	9.4	102.6	
		2012-07	0.0		
		2012-08	0.0		
		2012-09	0.8		
		2012-10	0.0		
		2012-11	0.0		
		2012-12	1.7		
		2013-01	0.9		
		2013-02	1.2		
		2013-03	0.7		
		2013-04	0.0		
		2013-05	3.9		
		2013-06	0.0		
		2013-07	0.0		
		2013-08	0.0		
		2013-09	0.0		
		2013-10	1.3		
		2013-11	0.0		
		2013-12	0.0		

TEC	Type MAF Code (OOMA)	Comp Year Month	Man-Hours (Monthly)	Man-Hours (MAF)	Man-Hours (TEC)
		2014-01	0.0		
		2014-02	0.8		
		2014-03	4.9		
		2014-04	6.9		
		2014-05	29.1		
		2014-06	4.5		
		2014-07	17.6		
		2014-08	3.2		
		2014-09	3.2		
		2014-10	6.5		
		2014-11	6.0		

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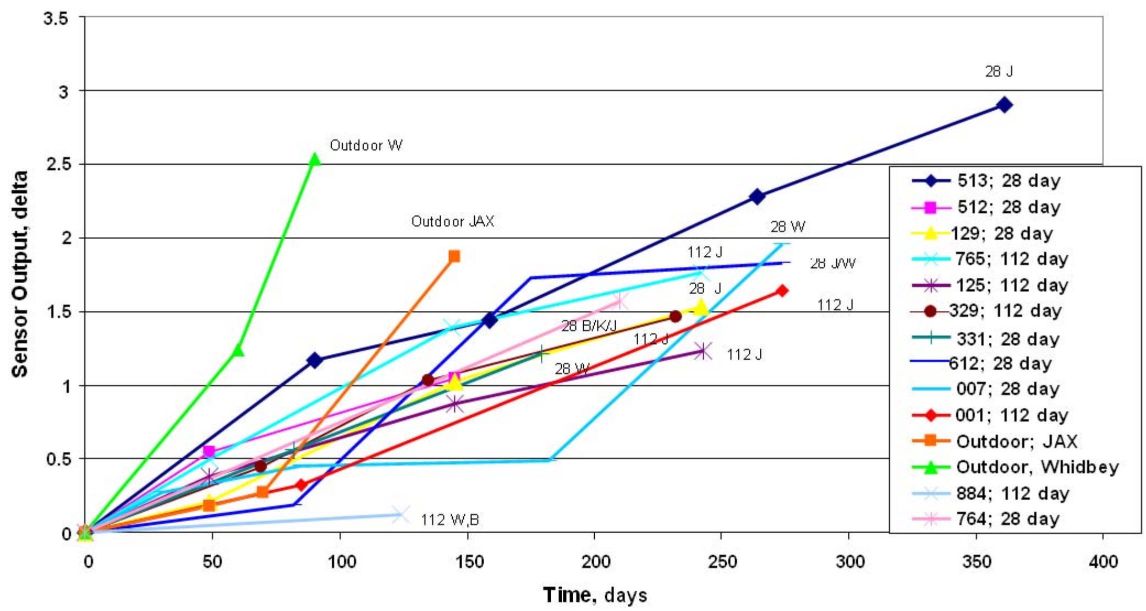
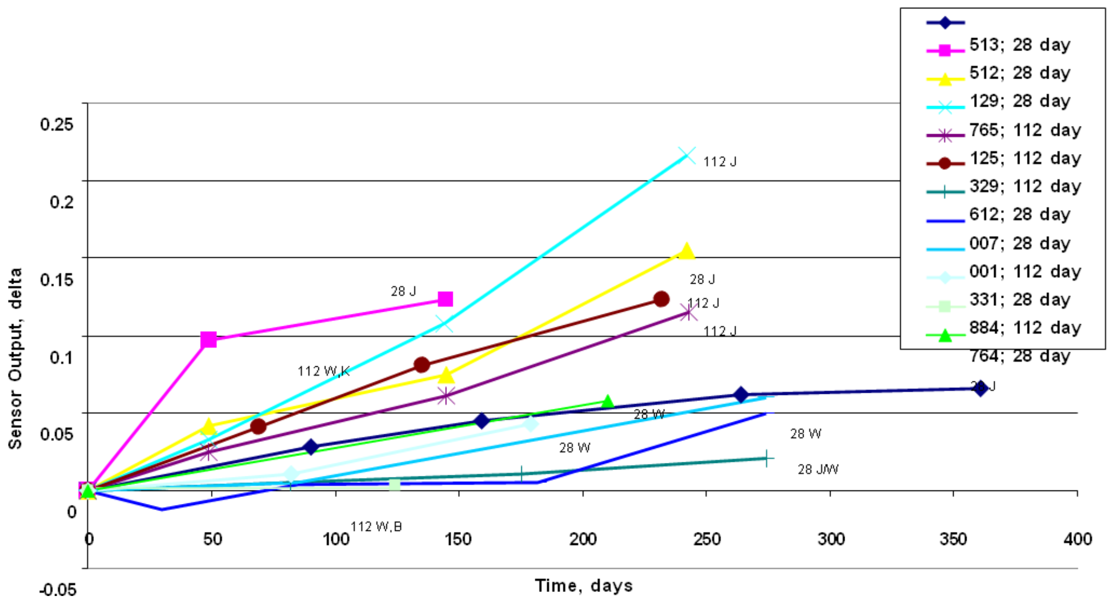
APPENDIX D. ADDITIONAL CORROSION SENSOR RESPONSE DATA

This figure contains the upper horizontal P-3 surface area corrosion sensor response for all aircraft. It also contains reference data for salt and humidity levels at the various P-3 operating bases. Sensor data was extracted at 28 days and 112 days for comparison and analysis. Plots along x axis are sensor outs and the y axis time in days. Data plots for outdoor storage in Jacksonville, as well as Whidbey, are also shown, which can be used as a comparison for a better understanding of habitat vs. natural shielding.



Sensor Response for Upper Horizontal; J=JAX; W=Whidbey; K= Kaneohe; B= Brunswick. Source: Abbott, Columbus, and Beals (2009).

This figure contains all the different corrosion sensor-monitoring points across the aircraft and indicates very little delta between the severity and cumulative corrosion sensor response between 28 and 112 days wash intervals.



Sensor Response for Port, Outboard, Flap Well; J=JAX; W=Whidbey; K= Kaneohe; B= Brunswick. Source: Abbott, Columbus, and Beals (2009).

APPENDIX E. NALCOMIS MPRA ACCEPTANCE MAN-HOURS

This table shows the NALCOMIS MPRA acceptance man-hours as analyzed by Wilson and Ball in 2014.

	EP-3E		P-3		P-8A			
	EMT	Man-Hours	EMT	Man-Hours	EMT	Man-Hours	EMT	Man-Hours
2012-01-03			1.9	3.4				
2012-01-05			3.3	10.5				
2012-01-06			9.4	11.4				
2012-01-09			39.6	57.5				
2012-01-10			31.6	39.9				
2012-01-11			28.8	40.4			0.7	0.9
2012-01-12			16.3	17.7				
2012-01-13			7.3	11.4				
2012-01-17			38.9	50.4				
2012-01-18			14.9	29				
2012-01-19			15.8	24.9				
2012-01-20			1.9	3.8				
2012-01-21			29	55.7				
2012-01-23			1.8	2.8				
2012-01-24			0.9	0.9				
2012-01-25			0.9	1.1				
2012-01-26			0.9	0.9				
2012-01-27			0.3	0.3				
2012-01-31			11.3	16.9			1.2	2.3
2012-02-01			4.1	7.1				
2012-02-02	0.7	0.7	10	19.2				
2012-02-03			6.9	16.4				
2012-02-04			5.9	11.7				
2012-02-06			3.8	6				
2012-02-07			2.9	4.6				
2012-02-08			5.5	8.9				
2012-02-09			3.3	5.3				
2012-02-10			2.2	5.3				
2012-02-13			25.8	38.9				
2012-02-14			6.2	8.4				
2012-02-15			11	28.1				
2012-02-16			193.6	683.7				
2012-02-17			0.8	1.1				
2012-02-18			6.3	14.1				
2012-02-22			12.6	21.1				
2012-02-23			18.7	29.1				

	EP-3E		P-3		P-8A			
	EMT	Man-Hours	EMT	Man-Hours	EMT	Man-Hours	EMT	Man-Hours
2012-02-24			12.4	21.3				
2012-02-25			13.5	13.5				
2012-02-26			0.8	1.6				
2012-02-27			26.3	70.3				
2012-02-28			28.8	60.4				
2012-02-29			29.3	52				
2012-03-01	0.5	0.5	26.5	86.6				
2012-03-02			16	30.2				
2012-03-05	8.5	18						
2012-03-06			5.1	12.9				
2012-03-07			8.8	14.5				
2012-03-08			1.2	1.2				
2012-03-09	3	3	0.4	0.4				
2012-03-12			21.3	47.3				
2012-03-17			1.1	1.1				
2012-03-19			0.7	0.7				
2012-03-22			2.8	2.8				
2012-03-26			1.3	1.6				
2012-03-27			10	23				
2012-03-28			12.7	22.9				
2012-03-29			17.2	47.1				
2012-03-30			10	24.6				
2012-04-01	0.9	2.7	0.2	0.2				
2012-04-02			14.5	28.9				
2012-04-03			5.1	7.3				
2012-04-04			12.3	15.6				
2012-04-05			3	6.3				
2012-04-06			3.6	9				
2012-04-09			9.7	13.9				
2012-04-10			0.5	1				
2012-04-11			1.4	1.4				
2012-04-12			19.6	23.8				
2012-04-13			2.2	4.4				
2012-04-15			1.2	1.8				
2012-04-16			3.7	5.5				
2012-04-17			1.2	1.2				
2012-04-18			0	0				
2012-04-19			7.6	14.2				
2012-04-20			23.9	64.8				
2012-04-23			14.9	30.6				
2012-04-25			8.2	15.6				
2012-04-26			5.2	14				

	EP-3E		P-3		P-8A			
	EMT	Man-Hours	EMT	Man-Hours	EMT	Man-Hours	EMT	Man-Hours
2012-04-28			0.4	0.4				
2012-05-02			1.5	1.5				
2012-05-03			5.4	10.2				
2012-05-06			11.8	19.9				
2012-05-09			2.4	2.4				
2012-05-10	0.3	0.6	4.1	6.3				
2012-05-11			1.5	2				
2012-05-14			0.7	1.4				
2012-05-15			1.4	2.4				
2012-05-16			2.9	3.3				
2012-05-17			5.9	19.8				
2012-05-18	0.5	1	22.7	31.8				
2012-05-21			25.2	26.7				
2012-05-22			9.7	12.9				
2012-05-23			6.7	7.8				
2012-05-24			37.3	45.1				
2012-05-25			23	27.6				
2012-05-26			14.4	18				
2012-05-27			1.9	2.3				
2012-05-28			8.4	33.3				
2012-05-29			7.4	12.3				
2012-05-30			2.4	2.4				
2012-05-31			7.7	12.4				
2012-06-01			3	3.8				
2012-06-02			1.8	3.6				
2012-06-03			3.4	3.7				
2012-06-04			0	0				
2012-06-05			1.4	1.9				
2012-06-06			12.8	32				
2012-06-07	0.7	0.7	0.7	0.7				
2012-06-08			7.1	11.5				
2012-06-09			18.4	44.2				
2012-06-11			12.8	24.3				
2012-06-12			9.8	14.7				
2012-06-13			5	12				
2012-06-14			138.6	288				
2012-06-15			42.5	76.1	3.3	5.8		
2012-06-16					5.3	6		
2012-06-17					1.4	2.8		
2012-06-18			10.7	17.2	5.8	17		
2012-06-19			1.6	2.6	4.3	9		
2012-06-20			9.8	11	8.6	20.2		

	EP-3E		P-3		P-8A			
	EMT	Man-Hours	EMT	Man-Hours	EMT	Man-Hours	EMT	Man-Hours
2012-06-21			4	9.2	7.8	23		
2012-06-22			12.1	17.7				
2012-06-23					2.9	3.3		
2012-06-24			1.2	2.2				
2012-06-25			1.9	3.2	8.5	26.8		
2012-06-26			2.3	2.9				
2012-06-27			0.5	0.5				
2012-06-28			11.6	16				
2012-06-29			5	5				
2012-06-30			0.5	0.6				
2012-07-02			15	20.1				
2012-07-03			9.2	18.4				
2012-07-05			14	32.5				
2012-07-06			4.7	6				
2012-07-07			2	2				
2012-07-09			12.3	15.4				
2012-07-10			25.3	100.3				
2012-07-11			5.6	6.6				
2012-07-12			1.4	3.6				
2012-07-13			1.2	1.2				
2012-07-16			11.3	24	2.9	7.5		
2012-07-17			3.8	5	3.7	9.6		
2012-07-18			5.7	8	5.3	7.7		
2012-07-19			5.6	8.7	4.7	4.7		
2012-07-20			15.5	56.1	5.7	13.6		
2012-07-21					1.4	2.9		
2012-07-22					3.5	4.5		
2012-07-23					4.5	13.6		
2012-07-24					9	14.4		
2012-07-25			3.4	3.4				
2012-07-28			2	3.1				
2012-08-01			27.9	35.9				
2012-08-02			1.3	2.8				
2012-08-03			5.3	5.3				
2012-08-07			15.3	30.7				
2012-08-10			3.7	7.7				
2012-08-12			0.5	0.8				
2012-08-13			12.1	12.9			7.2	7.2
2012-08-14			11.7	46.4				
2012-08-15			0.9	2.7				
2012-08-16			1.4	1.8				
2012-08-17			2.7	2.9				

	EP-3E		P-3		P-8A			
	EMT	Man-Hours	EMT	Man-Hours	EMT	Man-Hours	EMT	Man-Hours
2012-08-21			2.9	7.2				
2012-08-22			3.9	6.9				
2012-08-23			3.9	5.7				
2012-08-24			8.9	9.3				
2012-08-27			10.6	13.8				
2012-08-28			3.8	3.9				
2012-08-29			16.3	19.8				
2012-08-30			93.3	127.7				
2012-08-31			1.4	1.4				
2012-09-04			0.6	1.1				
2012-09-05			3.1	3.8				
2012-09-06			10.4	53.4				
2012-09-07			1	1				
2012-09-10			2.7	3.2				
2012-09-11			0.4	0.4				
2012-09-12			17.3	25.9				
2012-09-13			20.3	23.1				
2012-09-14			6.9	13.5				
2012-09-17			9.2	10				
2012-09-18			4.7	8				
2012-09-19			9.3	17				
2012-09-22			3.1	4.3				
2012-09-23			0.3	0.3				
2012-09-24			0.9	4.4				
2012-09-25			7.1	7.6				
2012-09-26			28.1	64.3				
2012-09-27			11.4	15.8				
2012-09-28			15.1	46.1				
2012-09-29			0.9	1.4				
2012-10-01			7.8	14				
2012-10-02			3	8.2				
2012-10-03			4	4				
2012-10-04			0.9	0.9				
2012-10-05			7.7	9.6				
2012-10-06			8.5	13.7				
2012-10-09			2.3	2.8				
2012-10-10			7	8				
2012-10-11			12.4	19.4				
2012-10-12			25.4	35.2				
2012-10-15			0	0				
2012-10-16			2.6	4.4				
2012-10-17			6.6	7.9				

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	EMT	Man-Hours	EMT	Man-Hours	EMT	Man-Hours	EMT	Man-Hours
2012-10-19			3.2	3.2				
2012-10-22			4.4	8.5				
2012-10-23			25.5	31.1				
2012-10-24			21.3	38.5				
2012-10-25			12.2	25.4				
2012-10-26			25	80.8				
2012-10-29			3.4	3.7				
2012-10-30			12.5	23.1				
2012-10-31			12.1	24.7				
2012-11-01			6.8	17.6				
2012-11-02			2.8	2.8				
2012-11-05			3.9	3.9				
2012-11-06			4.1	13.8				
2012-11-07			0.6	0.6				
2012-11-09			0	0				
2012-11-11			0	0				
2012-11-14			6.7	6.9				
2012-11-15			8.8	11.3				
2012-11-16			13.2	25.5				
2012-11-17			3.3	4.5				
2012-11-19			13.4	17.9				
2012-11-20			10.4	22.6				
2012-11-23			1.3	1.3				
2012-11-24			3.8	5.7				
2012-11-26			0.5	0.5				
2012-11-27			28.3	53.8				
2012-11-28			24.4	34.5				
2012-11-29			23.4	83.8				
2012-11-30			36.8	48.4				
2012-12-01			0	0				
2012-12-02			0.5	0.8				
2012-12-03			5.3	8.6				
2012-12-04			5.1	9.5				
2012-12-06			0.5	0.5				
2012-12-07			0.8	0.8				
2012-12-08			1.5	4.5				
2012-12-11			0	0				
2012-12-17			6.9	8				
2012-12-19			0.6	0.6				
2012-12-20			5.1	9.9				
2012-12-21			30.5	45.6				
2012-12-23			0.5	1				

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	EMT	Man-Hours	EMT	Man-Hours	EMT	Man-Hours	EMT	Man-Hours
2012-12-24			14.2	19.1				
2012-12-26			122.4	124.4				
2012-12-28			5.1	9.5				
2012-12-31			1.8	1.8				
2013-01-02			0	0				
2013-01-08			3.3	3.8				
2013-01-09			3.9	7				
2013-01-10			26.9	52.7				
2013-01-11			2.1	2.8				
2013-01-14			5	10				
2013-01-15			19.5	21.9				
2013-01-16			12.1	17.9				
2013-01-17			42.7	54.8	0.6	0.6		
2013-01-18			5.4	5.4				
2013-01-19			15	26.8				
2013-01-20			41	44.8				
2013-01-21			34.1	50.8				
2013-01-22			0.9	2.2	5.4	11.1		
2013-01-23			7.9	12.7				
2013-01-24			0.2	0.4				
2013-01-25			14	15.4				
2013-01-28			2.9	5.6				
2013-01-29			5.8	8.5				
2013-01-30			10	12.3				
2013-01-31			37.9	60.1				
2013-02-01			14.7	23.6				
2013-02-04			2.1	2.1				
2013-02-05			4.1	4.7				
2013-02-06			7.4	16.5				
2013-02-07			0.2	0.4				
2013-02-08			9.1	14.2				
2013-02-09			0.2	0.4				
2013-02-10	0.7	2.1						
2013-02-11	0.2	0.2	4.6	9.4				
2013-02-12	0.5	0.5	4.5	5.3				
2013-02-14			3.6	4.2				
2013-02-15			5.1	10.3				
2013-02-19	5.6	5.6	13.8	19.4				
2013-02-20			11.7	41.7				
2013-02-21			39.8	46.3				
2013-02-22			18.6	38.4				
2013-02-23			5.3	6				

	EP-3E		P-3		P-8A			
	EMT	Man-Hours	EMT	Man-Hours	EMT	Man-Hours	EMT	Man-Hours
2013-02-24	7.5	7.5						
2013-02-25			17.9	78.2				
2013-02-26			36.4	103.6				
2013-02-27			12.5	35.7				
2013-02-28			19.7	51.7				
2013-03-01			14.2	23.5				
2013-03-03			0.5	1				
2013-03-04			5.6	7.8				
2013-03-05			22.6	36.1				
2013-03-06			4.8	12				
2013-03-07			28.8	122.7				
2013-03-08			1	2				
2013-03-12			1	1				
2013-03-13			11.5	17.5				
2013-03-14			5.4	8.6				
2013-03-15			3.3	7.9				
2013-03-16			1	2				
2013-03-18			10.9	17.5				
2013-03-20			7.8	25.8				
2013-03-21			3.7	3.7				
2013-03-22			1.1	2.2				
2013-03-25			11.3	11.3				
2013-03-26			21	21.7				
2013-03-27			18.8	18.8				
2013-03-28			12.3	43.3				
2013-03-29			20.6	35.4				
2013-03-30			2.1	2.6				
2013-04-01			8.3	9.9				
2013-04-02			1.8	1.8				
2013-04-03			4.4	6.1				
2013-04-04			7.5	8.4				
2013-04-05			19.3	20.6				
2013-04-08			13.1	21.9				
2013-04-09			10.4	22				
2013-04-10			10.8	14.5				
2013-04-11			0.8	1.6				
2013-04-12			5.6	12.1				
2013-04-14			2.2	2.9				
2013-04-15			2	2				
2013-04-16			4.3	12.9				
2013-04-17			0.2	0.2				
2013-04-18			10.7	30.2				

	EP-3E		P-3		P-8A			
	EMT	Man-Hours	EMT	Man-Hours	EMT	Man-Hours	EMT	Man-Hours
2013-04-19			14	26.2				
2013-04-20			0	0				
2013-04-22			58.7	166.6				
2013-04-23			7.4	12.7				
2013-04-24			9.1	19				
2013-04-25			18.3	21.3				
2013-04-26			0.2	0.2				
2013-04-29			1.2	2.2				
2013-04-30			0.6	0.6				
2013-05-01			14.3	14.3				
2013-05-02			2.4	2.4				
2013-05-03			0.3	0.6				
2013-05-04			12.7	29.1				
2013-05-06			4	4				
2013-05-07			7.9	7.9				
2013-05-08			9	9				
2013-05-09			11.9	13.3				
2013-05-12			3.4	5				
2013-05-13			0	0				
2013-05-14			0.5	0.5	30.8	30.8		
2013-05-15					1	2		
2013-05-16			8.9	13.4				
2013-05-17			12.9	45.2	2.3	4.3		
2013-05-18			4.1	4.3				
2013-05-19			7.6	13.7				
2013-05-20			0.1	0.2				
2013-05-21			15.6	27				
2013-05-22			0.7	0.7				
2013-05-24			5.5	7.9				
2013-05-25			14.1	23				
2013-05-26			11.2	12.7				
2013-05-27			10.3	10.3				
2013-05-28			1.3	1.4				
2013-05-29	0.3	0.3	27.9	46.6				
2013-05-31			7	10.3				
2013-06-01			0	0				
2013-06-02			3.4	3.6				
2013-06-03			35	75.1				
2013-06-04			12.1	17				
2013-06-05			9.4	23.5				
2013-06-06			37.7	74.6				
2013-06-07			5.9	6.4				

	EP-3E		P-3		P-8A			
	EMT	**Man-Hours**	**EMT**	**Man-Hours**	**EMT**	**Man-Hours**	**EMT**	**Man-Hours**
2013-06-09			1.5	1.5				
2013-06-13			0.4	0.4				
2013-06-14			0.2	0.2				
2013-06-17			1.6	1.6				
2013-06-18			0.9	0.9				
2013-06-19			0	0				
2013-06-20			0.9	0.9	0.8	1.6		
2013-06-26			0.8	0.8				
2013-07-01			0.5	1				
2013-07-02			2.4	4.8				
2013-07-08			1.4	4.2				
2013-07-09			2.1	2.1				
2013-07-10			0.6	1.2				
2013-07-13			0.8	0.9				
2013-07-16			6.8	9.2				
2013-07-17			0.5	1	0.6	1.2		
2013-07-18			0.2	0.2				
2013-07-21			0.2	0.2				
2013-07-22			0.5	0.6				
2013-07-26			2	4				
2013-08-07			45.3	87				
2013-08-12			2.7	2.7				
2013-08-20			5.4	9.2				
2013-08-23			0.8	1.5				
2013-08-26	4	8						
2013-08-27	40.9	50.5	0	0				
2013-08-28	0.5	1						
2013-08-30			0.2	0.2				
2013-09-04			0.3	0.3				
2013-09-05	0	0						
2013-09-06			2	3.2				
2013-09-07			1.1	2.2				
2013-09-09			182.6	232.7				
2013-09-10			13.2	17.7				
2013-09-11			5.1	9.8				
2013-09-12			7.8	10.4				
2013-09-16			0	0				
2013-09-17			12.2	34.4				
2013-09-18			4.5	8.6				
2013-09-19			6.6	9.2				
2013-09-23			12.5	21				
2013-09-24			1.4	2.8				

	EP-3E		P-3		P-8A			
	EMT	Man-Hours	EMT	Man-Hours	EMT	Man-Hours	EMT	Man-Hours
2013-09-26			0.6	0.6				
2013-09-30			0.9	0.9				
2013-10-01			0.9	0.9				
2013-10-02			0.4	0.4				
2013-10-03			37.8	87.9				
2013-10-04			12.1	18.6				
2013-10-08			2.2	3.4				
2013-10-10			5.7	9.7				
2013-10-15			1.4	1.6				
2013-10-17			5.1	10				
2013-10-18			0.9	0.9				
2013-10-23			4.9	6.5				
2013-10-24			1	3				
2013-10-25			0.9	1.2				
2013-10-28			3.4	4.4				
2013-10-29			14.5	21	1.7	3.4		
2013-10-30			4.2	7.4				
2013-10-31			2.8	5.6				
2013-11-01			7.9	18.1				
2013-11-02			7.1	14.2				
2013-11-03			77.3	141.2				
2013-11-04			6	9.5				
2013-11-06			2	3.7				
2013-11-07			4.1	4.1	13	29.9		
2013-11-08			1.6	1.6	18.7	53.7		
2013-11-09			0.6	1.2				
2013-11-11			2.2	3.4				
2013-11-12			0.4	0.4				
2013-11-13			1.2	1.2				
2013-11-14			2.2	2.2				
2013-11-15			0.5	0.5				
2013-11-16					6.2	16.1		
2013-11-17					19.4	70		
2013-11-18			17.1	34.2	20.2	65.5		
2013-11-19			20.2	36				
2013-11-20			41	101.6				
2013-11-21			5.1	9.3				
2013-11-22			94.9	216.3	5.8	16		
2013-11-23			2.3	3.9				
2013-11-24			4	5.1	9.5	20.3		
2013-11-25					4.2	9.6		
2013-11-26			6.8	14.2				

	EP-3E		P-3		P-8A			
	EMT	**Man-Hours**	**EMT**	**Man-Hours**	**EMT**	**Man-Hours**	**EMT**	**Man-Hours**
2013-11-27			3.2	5.4	23.2	57.9		
2013-11-29			6.1	6.1				
2013-12-02			3.9	5.6				
2013-12-03			4.1	6.1				
2013-12-04			3.4	4.9				
2013-12-05			3.4	6.5				
2013-12-06			0.5	0.5				
2013-12-07			2.1	6.3				
2013-12-09			3	9.5				
2013-12-10			4.9	11.4				
2013-12-11			6.5	10				
2013-12-12			1	1.2				
2013-12-13			0.9	0.9				
2013-12-15			0.7	0.7				
2013-12-17			2.4	2.4				
2013-12-23			4.4	8				
2013-12-27			31.3	46.7				
2013-12-30			2.7	3.2				

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